SOME STUDIES ON THE STABILIZATION OF PANKI POND ASH WITH CHEMICALS AND RANDOMLY ORIENTED FIBERS AND ITS STRENGTH CHARACTERISTICS

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SOME STUDIES ON THE STABILIZATION OF PANKI POND ASH WITH CHEMICALS AND RANDOMLY ORIENTED FIBERS AND ITS STRENGTH CHARACTERISTICS

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By

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To the
Department of Civil Engineering
Indian Institute Of Technology Kanpur

KANPUR

DEDICATED TO

MY MOTHER, FATHER AND BROTHERS:

CERTIFICATE

It is certified that this work entitled "**Some studies on the stabilization of panki pond ash with chemicals and randomly oriented fibers and its strength characteristics**", by Ekambram Gunti has been carried out under our supervision and that this work had not been submitted elsewhere for the award of any degree.

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Abstract

The thesis pertains to the strength and deformation behavior of Panki pond ash stabilized with chemicals like lime, sodium chloride and randomly oriented fibers. The experiments were conducted in different phases. First the optimum moisture content and the corresponding maximum dry density is obtained by Harvard miniature compaction method. Once the maximum possible strength is achieved by compacting the Panki pond ash at 34% moisture (OMC), chemical stabilization of the same is tried by adding quick lime and sodium chloride in sequence. First by adding different quantities of lime with a fixed amount of dry pond ash and optimum moisture content, samples are prepared by using Harvard miniature compaction method and unconfined compression test on samples were carried out. From these tests optimum dosage of lime (12%) is found. Then samples were made by adding optimum water content, lime and different quantities of sodium chloride with pond ash and compacting to find the optimum dosage (1%) of sodium chloride. Finally samples are made by adding three different types of geosynthetic fibers of three different lengths with fixed amount of dry pond ash, and optimum quantity of water content, lime and sodium chloride and compacting the same. The optimum length and optimum fiber content (0.6%) to achieve maximum strength was found by testing the above samples and finding the unconfined compressive strength. It is found that Garlon-GW3 at 5 mm length gives the maximum strength.

Subsequently California Bearing Ratio tests were made on samples prepared at optimum water content, lime and sodium chloride and also fiber material. It is found that fiber additive increased the CBR values significantly. Thus the pond ash which is otherwise a waste material when stabilized using the chemicals and fibers as stated earlier can be used as subgrade material for road construction. It also increased its ductility as indicated by the increased value of failure strain corresponding to the peak strength values.

Drained, Undrained and quick triaxial tests also showed increased values of cohesive and angle of shearing resistance. Through Electron micrograph studies on the samples stabilized with different admixtures, explanation could be made for the increased strength.

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EKAMBRAM.GUNTI

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G	Specific gravity
$(\gamma_d)_{max}$	Maximum dry density at optimum moisture content
q_u	Unconfined compressive strength of the soil
A_I	Initial area of specimen
ξ	Strain
A_c	changed area at any stage
σ_1	Major Principal Stress
σ_3	Minor principal stress
C^1	effective cohesion
Φ^1	Effective internal friction angle
ΔV	Volume change
V	Initial volume
σ_d	Deviator stress
U	pore pressure
$\sigma_1^{\ 1}$	Effective major principal stress
$\sigma_3^{\ 1}$	Effective minor principal stress

Abbreviations

FA	Fly ash
SEM	Scanning Electron Microscope
OMC	Optimum Moisture Content
OLC	Optimum lime Content
OFC	Optimum Fiber Content
OSC	Optimum sodium chloride
UCT	Unconfined Compression Test
CD	Consolidated drained test
CU	Consolidated undrained test
CBR	California bearing ratio
UCS	Unconfined compressive strength

CHAPTER 1

INTRODUCTION

1.1 General:

Due to commissioning of large coal based thermal power stations to meet the increased demand of power, the production of fly ash in India has increased phenomenally to about 100 million tones per year. But hardly about 10 % of the total production of fly ash is utilized for gain-full applications. Most of this amount is of poor quality that is transported and stored in ash dykes spread over large areas. As this pond ash is not of much use, over the years the ash dykes are completely filled. It necessitates raising them further to enhance their storage capacity. In many places crest level of these ash dykes have been raised to a level more than 20 meters. As ash disposal is made in a slurry form, huge amount of water is also released in doing so. As such, ash dykes should be designed to take care of the same. If proper design and maintenance of ash dykes are not adopted breaches may very often occur releasing huge amount of ash slurry to the neighbor hood areas causing pollution problems. The storage of ash can is made either by raising the present ash dyke or by acquiring new areas and building new ash ponds there. The first proposition has many problems and it can be raised only to a limited level. Acquiring new areas may not be always possible because of scarcity of land in the neighborhood of existing power stations. Therefore a strategy for the proper and efficient management of this huge quantity of waste pond ash material needs to be developed. If this waste material could be used in large quantity in the construction of embankments, filling of low lying areas as a part of land reclamation and making of bricks the problem could be overcome to a great extent. Some efforts are already made in making fly ash bricks. But the technology for the extensive use of pond ash in Geotechnical engineering projects has not yet been fully developed.

Conventional methods e.g. compaction, chemical stabilization with lime, sodium salts etc for improving the engineering properties like increasing shear strength decreasing the compressibility and permeability of geo-materials can be adopted. In recent years lot of attention has been paid to the chemical stabilization of pond ash. Use of discrete fibers and meshes oriented either randomly or in particular direction for improving the behavior of geo-materials is an attractive alternative. Several investigators have worked in this area and contributed significantly. A brief review of the literature on the subject is presented in the following section.

1.2 Brief Review of Literature:

Studies have been conducted on Panki pond ash by several investigators for its characterization and improvement in its engineering behavior (Das, 1992; Singh, 1989; Bhora 1982; Yudhbir et al., 1989). In addition to Panki fly ash, Das (1992) also studied the behavior of fly ashes from Neyveli and Parichha. Mishra and Garg (1985) explored the possibility of its use in mined out land reclamation. Shukla and Gokhale (1995) tried to use it along with lime and gypsum as additive to lateritic soils to improve its engineering properties.

Srivastava et al. (1995) explored the utilization of industrial wastes (Fly ash and lime sludge) in combination for stabilizing Gangetic alluvial soils. He observed the best combination to be 8% fly ash as admixture with soils and 8% fly ash, 12% lime sludge with soils.

Sivapullaiah et al. (1995) estimated the optimum lime content by adding limes in different proportions to certain fly ashes to achieve maximum strength. They concluded that at the optimum lime content, formation of maximum amount of silicate hydrate occurs manifesting in the increased strength. Sivapullaiah et al. (1998) observed that fly ashes containing sufficient amount of lime content together with reactive silica develop good strength on the addition of water; but fly ashes containing only reactive silica, with insufficient lime content, develop improved strength only with hydrated lime.

Sivamohan and Ramesh (1999) carried out Unconfined Compression (UC) test on flyash collected from Rayalaseema thermal power plant. Their tests results showed that the strength of flyash could be improved by the addition of lime, but only up to the optimum lime content and the addition of sodium salts increase the pozzolanic reaction compounds. This can be attributed to the production of more gelatinous compounds due to increased pH.

Ramesh et al. (1999) studied the effect of addition of lime and sodium salts on the strength behavior of fly ash collected from Royalseema Thermal Power Plant. They observed that with addition of sodium salts to fly ash- lime mixture there is further increase in its strength. Maximum increase in strength was obtained with sodium hydroxide in comparison to sodium chloride and sodium sulphate.

Pandian and Krishna (2001) studied the effect of murrum addition on the Load-Penetration behavior quantified by California Bearing Ratio (CBR) of Fly ash collected from Raichur Thermal power plant, Karnataka for both unsoaked and soaked conditions; the study indicated significant increase in the CBR value.

Pandian et al. (2002) studied the effect of Fly ash addition with Black Cotton (BC) soils and Murrums and observed that such additions improve the CBR value significantly (30% to BC soils and 20% to murrum).

Narendra et al. (2003) investigated the effect of adding lime and sodium chloride with lignite fly ash obtained from Neyveli and estimated the optimum lime content and found that maximum increase in strength is about 30% in the presence of 1% sodium chloride.

Inclusion of randomly oriented discrete fibers as additives to soils for improving its engineering behavior has been highlighted as early as 1979 by Hoare. Subsequently many investigators (Hoover et al, 1982; Gray and Ohashi, 1983; Setty and Rao, 1987; Shewbridge and Sitar, 1989; Maher and Gray, 1990; Bauer and Fatani, 1991; Al-Refeai, 1991; Maher, 1994; Gown and Mercer, 1994; Maher and Ho, 1994; Charan, 1995; Raman et al, 1996; Michalowski and Zhao, 1996; Nataraj and McManis, 1997; Cosoli et al, 1998; Santoni et al, 2001) studied the effect of addition of synthetic fibers oriented either in particular directions or randomly on the behavior of such composites. They concluded that the same has great potential in airfield and road applications. Makiuchi and Mimegishi (2001) found that toughness and ductility of fiber-reinforced soils are beneficial for anti earthquake geostructures.

Morel and Gourc (1997) used randomly oriented and vertically oriented polypropylene mesh elements to reinforce sands and study the strain field under plane strain and the effect of reinforcement content on the specimen strength. They concluded that localization of strain does not affect the strength of the reinforced sand.

Application of randomly oriented synthetic fibers in improving the engineering characteristics has been reported by Chakraborty and Dasgupa (1995), Puppula et al. (1999), Kaniraj and Havanagi (2001), Kaniraj and Gayathri (2003). Chakraborty and Dasgupta (1995) used fly ash from Kolaghat Thermal Power Station and observed that 3 to 4% addition of polymer fibers increase the friction angle resulting in increased strength fly ash- fiber composite.

Puppula et al. (1999) conducted UC tests on Irving clays mixed with fly ash and polypropylene fibers. Based on the experimental data they concluded that fly ash has potential to reduce the plasticity characteristics and free swell behavior of soils. Mechanism that cause decrease in Plasticity Index (PI) values are due to cation exchange which lead to flocculation and decrease in double layer thickness around fine-grained particles, and concluded that beyond optimum fiber dosage (0.3%) the unconfined compressive strength values are decrease because the loss in cohesive strength was not compensated by large amount of occupied soil particles positions.

Kaniraj and Havanagi (2001) studied the behavior of cement-stabilized fiber-reinforced fly ash-soil mixture and observed that the fiber inclusion increase the strength of the raw fly ash soil specimen as well as the cement stabilized specimens. This also changes their brittle behavior to ductile behavior.

Kaniraj and Gayathri (2003) found that fiber inclusions make the fly ash-fiber specimens highly ductile, failure strain being about 1.5 to 2.5%. Fly ash was collected from Rajghat and Dadri power plants. Polyster fibers of two different types and a constant fiber content of 1 % were used. The results of compaction tests, tri-axial shear tests showed that the fiber inclusions increased the strength of the fly ash specimens, changed their brittle behavior into ductile behavior and length of fiber seems to have an influence on the behavior of specimens. In UC tests specimens attained a distinct failure stress at an axial strain of 1.5 to 2.5 % and in Unconsolidated Undrained (UU) and Consolidated Drained (CD) test it was in the range of 11 to 16 %. They further concluded that the failure envelope obtained from UU test is bilinear.

1.3 Scope of the present study:

The review of the literature on the subject reveals that use of compaction, chemical additives, fibers and meshes improve the properties of soils and fly ashes significantly. Extensive work has been reported on the improvement of behavior of sands using synthetic fibers or meshes either aligned in a particular direction or randomly oriented. But improvement of the engineering properties of fly ashes with randomly oriented fibers has not drawn much attention; more work is available on the chemical stabilization of the same. The studies that have been carried out so far, have focused only on a particular method out of all the possibilities as listed above. Thus there is a scope to study the maximum cumulative improvement in engineering properties like shear strength (drained and undrained), CBR value etc. using all the above methods together. Such a study has been under taken in the present thesis. The general organization of the thesis is described below.

1.4 Organization of the Thesis:

In chapter 2 general description of the materials used for the study and details of the experiments conducted, test procedures and their description with number of tests performed are presented.
In Chapter 3 experimental observations, discussions on the test results and the conclusions made are reported.
In Chapter 4 generalized conclusions and scope of future studies are made.

CHAPTER.2

MATERIALS USED AND PLANNING OF EXPERIMENTS

2.1 Panki Fly ash:

Fly ash as discharged in the pond area by the Panki Thermal Power Plant, Kanpur, India (henceforth termed as Panki pond ash in this investigation) has been used in this study. It has been reported in Chapter 1 that many investigators have studied the characteristics of the Panki pond ash.

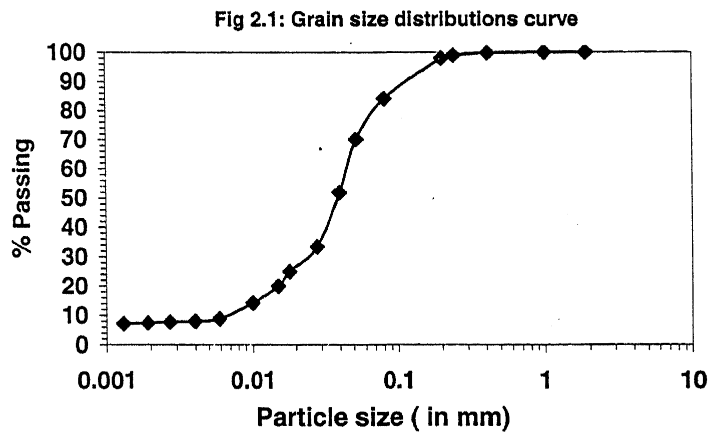
The general chemical composition of the pond ash has been analyzed by gravimetric method and reported by Singh (1989). It should be noted that there might be some variation in the percentage of the chemical constituents from batch to batch. The same is reported in Table2.1 and can be seen from there that the lime content (CaO) is very small and negligible. Therefore it is of poor quality. The total amount of sum of the oxides is more than 70%; the Panki pond ash thus can be categorized as Class-F fly ash.

Table 2.1: Chemical Composition of Panki Fly ash

Minerals	Percentage
SiO_2	57.6%
Al_2O_3	23.9%
Fe_2O_3	9.4%
CaO	0.86%
MgO	0.44%
SO_3	0.45%
Loss at 900^0C + Carbon	6.8%
Alkalies	0.55%

The grain size distribution of this pond ash is shown in Figure 2.1.

Figure 2.1:Grainsize distribution of this pond



The other physical properties as determined in the laboratory are presented in Table 2.2.

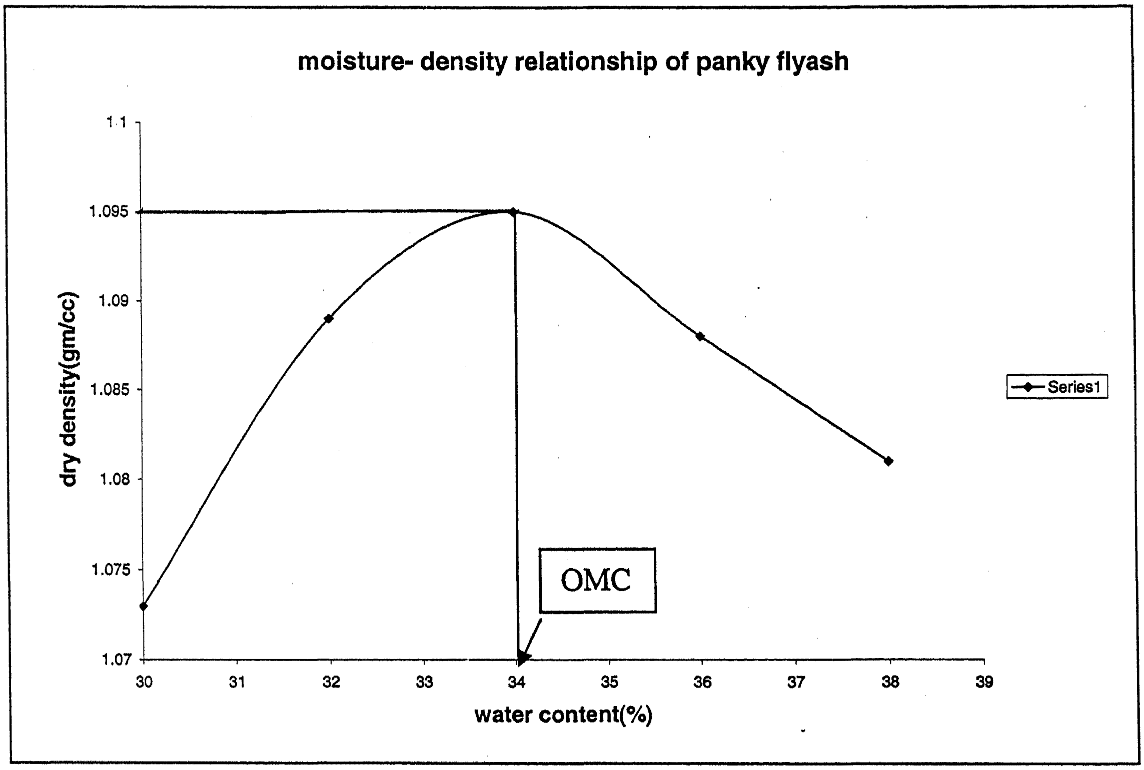
Table 2.2: Physical properties of Panki pond ash:

Specific gravity	-------	2.17
Grain size distribution data:		
a) Clay (< 0.002 mm)	--------	18 %
b) Silt (0.002 mm to 0.075 mm)	---------	73 %
c) Sand (0.075 mm to 2 mm)	----------	11%
d) C_u: Uniformity Coefficient	----------	5.85
e) C_c: Coefficient of Curvature	-----------	1.84
Optimum dry density and moisture content (Harvard miniature Compaction test):		
a) $\gamma_{d\ max}$	-----------	1.095 gm/cc
b) Optimum moisture content (OMC)	---- ------	34%
Variable head permeability test data:		
a) Coefficient of permeability	--------	1.984 $X10^{-5}$ cm/ sec

The grain size distribution shows that the particles are predominantly of silt size. Optimum moisture content and the corresponding maximum dry density as determined from Harvard miniature compaction test is also reported in Table2.2.

The moisture density, optimum moisture content and optimum dry density, relationship of panki fly ash are shown in Fig.2.2.

Figure2.2: moisture density relationship of panki pond ash



The average value of the moisture content and the corresponding dry density are plotted in the figure. From Fig.2.2 it is observed that the value of the optimum moisture content (OMC) and the corresponding maximum dry density ($\gamma_{d\ max}$) are 34 % and 1.095gm/cc respectively.

Thus maximum dry density that can be achieved is quite low. Total five tests were conducted to find the average value of the OMC and $\gamma_{d\ max}$. Scanning electron micrograph of the Panki pond ash (Plate.2.1 and Plate.2.2) show that it is composed of hollow cenospherical particles. As the particles are hollow it absorbs more water. This explains the reason for low dry density and high optimum moisture content.

The average value (computed from five tests) of the permeability of the fly ash compacted at OMC using variable head permeameter is found to be 1.984 $X10^{-5}$ cm/ sec. The obtained value of the coefficient of permeability is consistent with the range of values that are obtained for silt size soils.

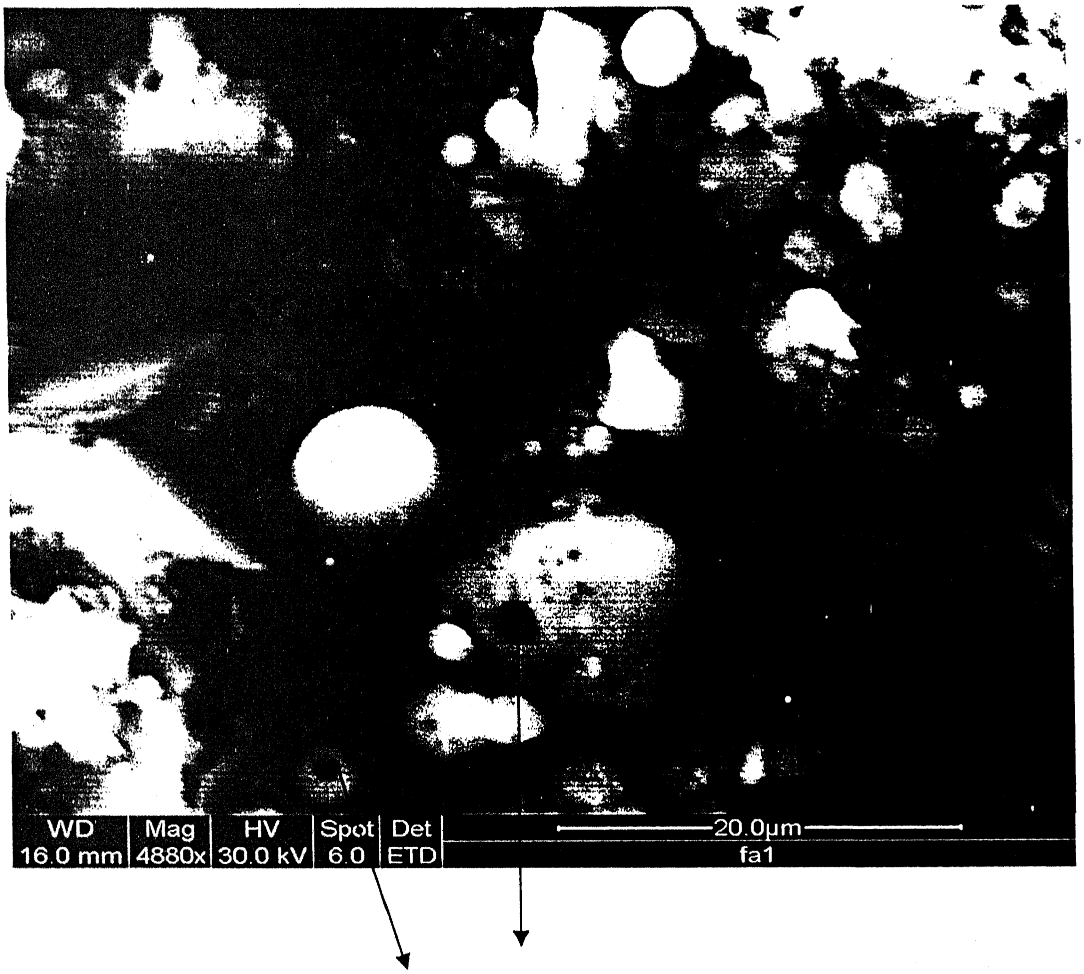


Plate 2.1: Hollow cenospherical particles of Panki pond ash:

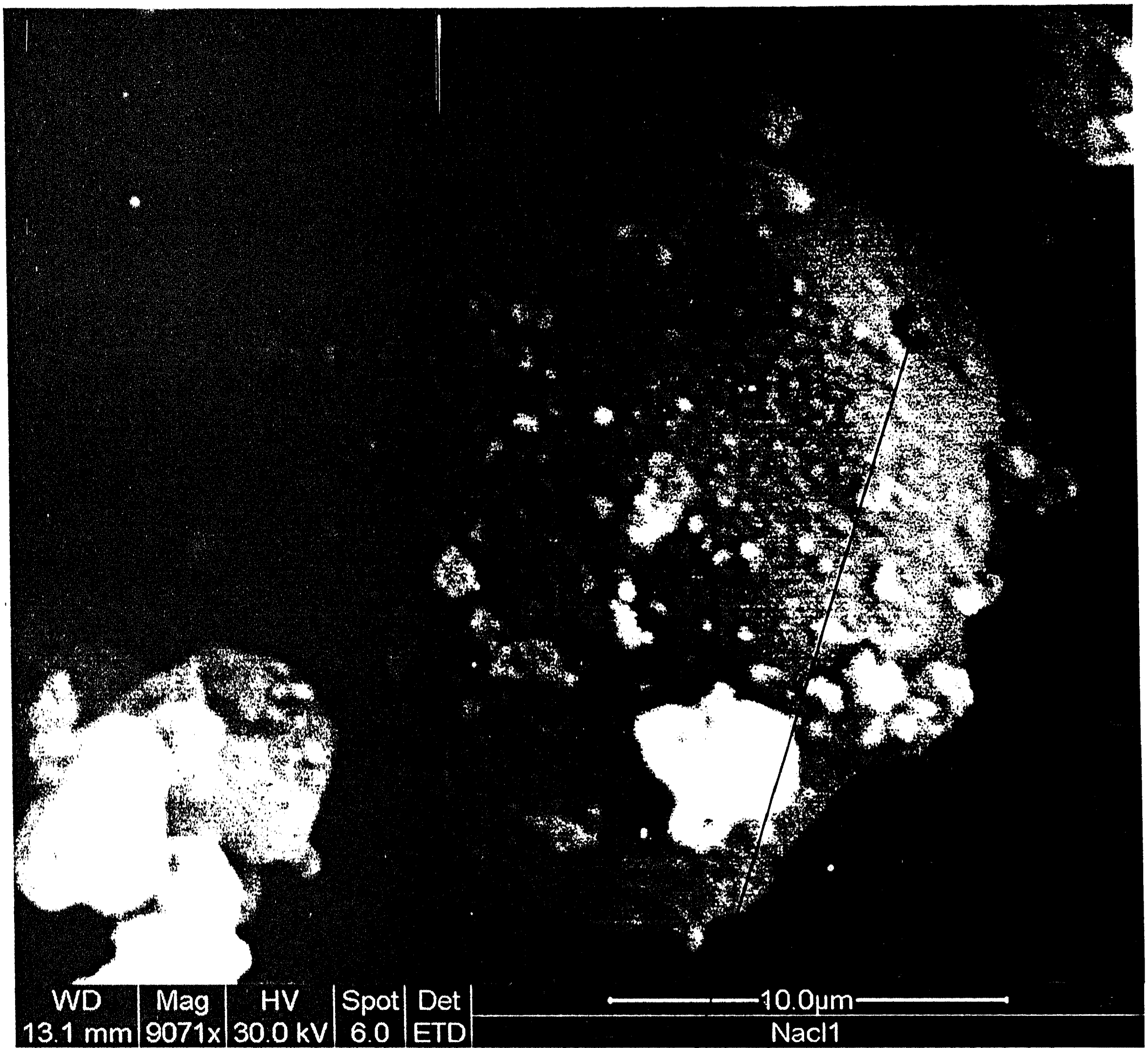


Plate 2.2: Hollow cenospherical particle of Panki pond ash:

2.2 Lime:

Chemical Composition of Lime procured from the market from MONOFIL CHEMICALS, suppliers of high-grade lime and lime-based products was found by gravimetric analysis in the Chemical Engineering Laboratory at I.I.T.Kanpur. The same is shown in Table 2.3 as follows. It can be seen from the table that the impurities in the lime is less than 10%.

Table 2.3: Chemical Composition of Lime

Minerals	Percentage
CaO	90.72%
SiO_2	1.80%
MgO	1.60%
Other impurities	5.88%

2.3 Sodium chloride:

The chemical admixure, Sodium chloride used for the present study was obtained from the Qualigens fine chemicals limited, Mumbai. The purity of Sodium chloride content after (ignition) is 99.5 % and the total percentages of impurities is less than 0.5%.

The maximum limits of impurities are shown in the table 2.4

Table 2.4: Chemical composition of sodium chloride

Minerals	Percentage
Ammonia (NH_3)	0.002%
Sulphate (SO_4)	0.02%
Iron (Fe)	0.002%
Potassium (K)	0.02%

2.4 Fiber:

Out of the three types of synthetic filaments used in the present study two of the reinforcing material is made of high tenacity Polypropylene geosyntheticfilaments manufactured by Garware – wall ropes limited, New Delhi. Theproperties of these two filaments were supplied by the manufacturing company. The third one is obtained from nylon ropes sold in local market. The tensilestrength and diameter determined in the laboratory.

Specifications of the fiber filaments are given below.

Item – GARLON NW –2

Breaking strength	7 Kgf approx. (±5 %)
Color	Natural white
Material	High tenacity polypropylene
Runnage (m/kg)	7000 (±5 %)
Diameter	1.34 mm

Item – GARLON GW –3

Breaking strength	4-5Kgf approx. (±5 %)
Color	Natural white
Material	High tenacity polypropylene
Runnage (m/kg)	9000 (±5 %)
Diameter	1.87 mm

Item – NYLON ROPE

Breaking strength	3 Kgf approx.
Color	Green
Diameter	1.12 mm

2.5 Planning of the Tests:

2.5.1 Sample Preparation:

Standard samples (38mm diameter and 76 mm high) are prepared using fixed amount of pond ash (300gms) for achieving the maximum dry density at the optimum moisture content (34%) without additives (as reported in Table 2.2) then subsequently mixing the same thoroughly with different chemical additives and fiber inclusions as follows:

i) Adding 8 %, 10 %, 12%. 14% of lime and water (34%) and compacting the mixture in the Harvard miniature split spoon sampler mould using standard procedure. From this series of tests optimum lime content at OMC (hence forth designated as OLC) is obtained. For each lime content 5 samples were tested.

ii) Samples are now prepared adding Sodium Chloride (0.5, 1 and 1.5% by weight of the amount of dry pond ash) and optimum contents of moisture (OMC 34%) and lime (OLC) and compacting it following the procedure as stated earlier. From the tests conducted optimum dosage for Sodium Chloride (OSC) in the presence of lime is determined

iii) Once the optimum contents of moisture and chemical additives are obtained, samples are made adding three different kinds of synthetic fibers (Nylon threads, Garlon GW3 and NW2) of three different lengths (0.5, 1 and 1.5 cm) at different percentages by weight (0.4, 0.5 and 0.6 %) and test were conducted to find the optimum level of fiber content (OFC) and its optimum length.

iv) Each of the samples so prepared were cured at 27^0 Celsius for 7, 14, 21, 28 days.

2.5.2 Tests Performed:

The following tests were conducted on the samples:

i) Unconfined compressive test
ii) California bearing ratio test: Unsoaked and soaked
iii) Consolidated Undrained Triaxial test with pore water pressure measurement
iv) Drained Triaxial test
v) Scanning electron Microscopy for studying the fabric
vi) Optical Microscopy for the synthetic fibers

It should be noted that all the tests were not performed on all the samples. Tests were conducted only as required depending on the requirement as a follow up of

the earlier tests. The list of the different tests and the number of tests that have been conducted are presented in Table 2.5 as follows.

Table 2.5: List of the different tests conducted

Serial number	Type of test conducted	Number of test conducted
1	Specific gravity	4
2	Grain size distribution analysis	3
3	Harvard miniature compaction test	5
4	Variable head permeability test	5
5	Gravimetric analysis	1
6	Unconfined compression test	
	a) Finding the optimum Content of Lime (8%, 10%, 12%, 14%)	20
	b) Finding the optimum Content of Sodium chloride (0.5%, 1%, 1.5%)	15
7	c) Finding the optimum Content of Fiber filaments Randomly Oriented	45
8	1) Garlon – GW.3 (0.5,1,1.5 cm Filaments)	15
9	2) Garlon NW.2 (0.5,1,1.5) cm Filaments)	15
10	3) Nylon Rope:(0.5,1,1.5 cm)	15
11	d) Finding the strength with	

	Curing (7,14,21,28 days) at Optimum content Of Lime (12%)	20
12	e) Finding the strength with Curing (7,14,21,28 days) at the optimum Content of Sodium chloride (1%)	180 Total
13	f) Finding the strength with Curing (7,14,21,28 days) at the optimum contents of Fiber filaments Randomly Oriented	
14	1) Garlon – GW.3 Filaments)	60 (4×5×3)
15	2) Garlon – NW.2 (Filaments)	60(4×5×3)
16	3) Nylon Rope Filaments)	60(4×5×3)
17	California Bearing Ratio test	8

18	Triaxial test	
	g) CU Test	36
	h) CU Test	(1×6×3)
		(1×6×3)
19		
	Scanning electron	
	Microscopy	6
20		
	Optical microscopic test	
		3

CHAPTER 3

EXPERIMENTAL OBSERVATIONS AND TEST RESULTS

3.1 Results and Discussions:

The stress strain diagram as obtained from unconfined compression test (I.S. Method) of the samples at OMC with different lime content and cured for different days are presented in Fig 3.1. The Test set-up is shown in photographic plate 3.1.

It can be seen from the figure that beyond a certain quantity of lime there is a corresponding decrease in the strength of the pond ash samples. In the inset of Fig 3.1 the variation of unconfined compressive strength with percentage of lime content is shown (All the samples were tested immediately after their preparation). It can be seen that optimum lime content is 12%. Plate no 3.1 and 3.2 show the magnified electron microscopic images of the pond ash samples stabilized by adding 12 % quick lime and 34 % moisture content and compacted. Scanning Electron Microscope device is shown in phographic plate No 3.2.

The plates show presence of calcium silicate gel (white and whitish portions) that binds the pond ash particles together. If we compare the Plate No 2.1 and Plate No 2.2 with the Plate No.3.1 and Plate No 3.2, we find that the void spaces are filled with calcium silicate gel. Plate no 3.2 shows the large portion of the image giving a picture how the void spaces are filled with the above gel. Calcium silicate gel on hardening imparts additional strength.

From literature we know that further increase in strength can be obtained by adding sodium chloride. Therefore to find the optimum dosage of sodium chloride for maximum gain in strength, 0.5, 1, and 1.5% of sodium chloride by dry weight of the original sample is added, thoroughly mixed with water and lime (OLC) to make samples and unconfined compressive strength tests were conducted. Here the tests were made without any curing. Tests were conducted and the results are presented in Fig.3.2 it could be seen that optimum sodium chloride (OSC) content is 1 % at which the value of q_u is maximum and is equal to 95 Kpa.

Electronic microscopic images of slides prepared by adding 12 % lime (OLC), 1% sodium chloride (OSC) and 34% of water content (OMC) with 300 gms of dry pond ash and thoroughly mixed and compacted in a Harvard miniature apparatus show (Plate no.3.3 and plate no.3.4) presence of Sodium-Calcium- Silicate gels which on hardening provides additional strength to the fly ash composite. Plate

3.5 gives the matrix of the total pond ash- gel composite. Plate 3.6 shows the same very clearly. Very often the pond ash particles (cenosphere) were enmeshed within the gel giving better bonds. If plate No 3.2 is compared with Plate No 3.5, it is found that void spaces were better filled with Sodium-Calcium-Silicate gel in the latter case over the other one.

Here after all the samples are made with following specifications:
First fixed amount of the following quantities are taken.
Dry pond ash: 300gms.
OMC =34% by weight
OLC =12% by weight
OSC = 1% by weight

There after synthetic filaments of different length (0.5, 1, 1.5 cm) of three different types (Nylon threads, Garlon-GW3 and Garlon-NW2 were mixed thoroughly with the soil, moisture, lime and sodium chloride as specified above and compacted to make the samples of standard dimensions.

Some samples are tested immediately after their preparation. The q_u verses ε diagram of the samples prepared by adding Garlon- GW3 fiber and tested with out any curing are presented in figures 3.3, 3.4 and 3.5 respectively. The optimum amount of fiber is observed as 0.6 % at 0.5 cm length. Similarly for Garlon-NW2 and Nylon threads for three different lengths the optimum amount of fiber content was determined and shown in Figs.3.6 to 3.11. In each of these figures, in the inset the determination of optimum fiber content is outlined. For Garlon-NW2 it is 0.4% but the same for Nylon threads is 0.5% at 1cm length each. The values of these for different length of the fibers, types of fibers at OMC, OLC, and OSC are listed in Table 3.1. It is seen from the tables that the maximum gain in strength is obtained with Garlon-GW3 filaments. Determination of the optimum of the fibers is shown in fig 3.12. For the Garlon-NW2 and Nylon filaments the optimum fiber length is found to be about 10 mm. For Garlon-GW3 filament could not be cut into sizes less than 5mm and the maximum strength is found to be obtained at that value.

Other samples are tested after curing the samples for 7,14,21,28 days. The unconfined test data are plotted and presented in Fig.3.13 to Fig.3.23.

It can be seen from the above Figures that more is the curing period, more is the strength of the samples. The maximum strength is reached after 28 days of curing period beyond which tests were not conducted. Variation of the unconfined compressive strength with lime content on the ultimate compressive strength of chemically stabilized pond ash with different curing period is shown in Fig 3.24.

Table No.3.1 Optimum Fiber Content
(OMC = 34 %, OLC = 12%, OSC = 1%.)

	LOF = 5 mm			LOF = 1.0 mm			LOF = 1.5 mm		
Type of fiber	OFC	q_u(Kpa)	ε_f %	OFC	q_u(Kpa)	ε_f %	OFC	q_u(Kpa)	ε_f %
Garlon-GW3	0.6%	159.24	2.8	0.5%	92.8	2.0	0.4%	75.18	1.9
Garlon-NW2	0.5%	96.37	1.7	0.4%	121.78	2.03	0.2%	104.8	1.9
Nylon rope	0.4%	104	1.97	0.5%	140	2.36	0.3%	128.4	2.03

LOF: Length of fiber; ε_f : Failure strain

Optimum lime content and the maximum value of the corresponding unconfined compressive strength can be evaluated from these graphs presented in Fig 3.24. It can be seen from the figure that effect of curing period have negligible effect on the optimum lime content. From the original 12 % optimum lime content obtained with out any curing, for 28 days curing period the same is 11.7 %, the difference being only 0.3%. These graphs also help in designing the lime content and the curing period for achieving a desired level of unconfined compressive strength. The same data is plotted in a different manner in fig 3.25 showing the variation of unconfined compressive strength with curing period for different lime content. It can be seen from the figure also that for a given lime content as a curing period increases the compressive strength increases.

In Fig 3.26 shows the variation of unconfined compressive strength with curing period with three different types of geosynthetic threads. The figure shows that the unconfined compressive strength of all the samples increases with curing period. The graphs showing the variation of strength with curing period for samples strengthened with nylon and Garlon-NW2 threads are very close to each other. further more, the increase in strength with curing period in gradual. In contrast to the above observation there is a sharp and substantial increase in the strength values when Garlon-GW3 threads are used. In order to find the reason for the same, optical microscopy of the threads was done which are presented in Plates 3.7 to 3.9.

Optical microscopic peak image of Garlon-GW3 (Plate No.3.7), Garlon-NW2 (Plate No.3.8) and nylon threads (Plate No.3.9) as shown in the above plates show that the garlon-GW3 has many overlapping filaments with void spaces in between within which fly ash particles and calcium and sodium silicate gel can form a very good bond (Plate 3.7). Surface of the Garlon- NW2 thread is wavy in the lateral

direction but in the longitudinal direction it is smooth (Plate 3.8). Thus there will be good frictional bonding on the surface of the thread with the pond ash particles. Nylon threads has smooth surface on the both the directions as seen from plate no 3.9. So it will have somewhat less frictional bond between particles and thread thus with Garlon-NW2 but as both have smooth surface in longitudinal direction Samples with Garlon-NW2 and Nylon threads show similar behavior in contrast to the sharp change of behavior for samples with Garlon-GW3.

The unconfined compressive strength q_u and their corresponding failure strain (ε_f %) of the all samples tested with different admixtures are presented in Table 3.2. It can be seen that strength (q_u) and the failure strain (ε_f %) increases substantially with addition of Garlon-GW3 in comparison to the admixtures. With curing substantial increase in the ductility of the stabilized pond ash samples with chemicals the maximum failure strain is 3%. But with Garlon-Gw3 it is 7%.

Plate No.3.10 shows the electron microscopic images of garlon GW3 enmeshed matrix of the pond ash and calcium-sodium-silicate gel. It can be seen that the formed gel and overlapping filaments together are tightly interlocked and, thus giving the higher strength. The unconfined compressive strength is least with nylon thread. There is a substantial increase in q_u values in Garlon GW3 in comparison to those obtained in nylon and Garlon-NW2 threads. The behavior so observed is consistent with the observations made regarding the bonding capacity.

Figure 3.27 shows a comparative study of the variation of q_u with curing period with chemically stabilized pond ash with lime, lime plus sodium chloride and fibers. It can be seen that there is substantial strength increase with addition of fibers. Adding Garlon GW3 fibres along with optimum content of chemicals (lime and sodium chloride) the maximum strength was obtained as 3400kPa where as the same obtained by adding optimum chemical contents (lime and sodium chloride) and only lime were 800 and 360KPa respectively. Strength of pond ash samples compacted at OMC was only 60kPA. The gain in strength of the stabilized samples with respect to the strength of the compacted pond ash are as follows:

STRENGTH VARIATION OF PANKI POND ASH WITH CURING

q_u = Unconfined compressive strength (KPa)
ε% = Percentage of failure strain
LOF = Length of filament

Table 3.2: Unconfined compressive strength and corresponding strain with curing

	0 – DAYS		7 – DAYS		14- DAYS		21 – DAYS		28-DAYS	
ADMIXURES ADDED :	q_u (kPa)	ε_f%	q_u (kPa)	ε_f%	q_u (kPa)	ε_f%	q_u (kPa)	ε_f%	q_u (kPa)	ε_f%
CaO	**114**	1.5	**164**	**1.52**	**288.7**	**1.7**	**308**	**1.7**	**334**	**1.79**
Nacl	**94**	1.7	**387**	**1.8**	**636**	**2.4**	**710**	**2.45**	**810**	**3**
Garlon.GW.3 LOF = 5 mm.	**159**	2.8	**1421**	**4.6**	**2269**	**6.05**	**2681**	**6.20**	**3419**	**7.05**
Garlon.GW.3 LOF = 10 mm.	**92.8**	2.0	**714.53**	**4.6**	**779.28**	**4.7**	**896**	**4.8**	**935**	**5.3**
Garlon. GW.3 LOF = 15 mm.	**75.18**	1.9	**574**	**3.5**	**684**	**3.5**	**722**	**4.5**	**864**	**5.3**
Garlon. NW.2 LOF = 5 mm.	**96.37**	1.7	**283**	**2.8**	**514**	**3.6**	**710**	**4.6**	**820**	**6.05**
Garlon. NW.2 LOF = 10 mm.	121.7	2.03	710	4.7	790	5.2	880	6.0	920	6.2
Garlon. NW.2 LOF = 15 mm.	**104**	1.9	**590**	**5.4**	**694**	**5.8**	**710**	**6.1**	**890**	**6.3**
Nylon Rope LOF = 5 mm	**104**	1.9	**336**	**5.3**	**363**	**5.5**	**418**	**5.6**	**501**	**5.9**
Nylon Rope LOF = 10 mm	140	2.3	452	6.0	547	5.8	769	6.0	829	**6.61**
Nylon Rope LOF = 15 mm	**128**	2.0	**212**	**4.05**	**524**	**5.3**	**537**	**4.8**	**634**	**6.05**

i) Pond ash+Lime+Sodium chloride+Fiber GW3: 52 times
ii) Pond ash+Lime+Sodium chloride: 12 times
iii) Pond ash +Lime: 6 times

The specimens after testing were photographed and on there the failure planes are marked as shown in photographic plates 3.3 to 3.5. Figs 3.3 and 3.4 shows failure planes along which the samples failed, with the addition of lime and sodium chloride when curing period is less or equal to 7 days there was no definite plane aling which the samples failed. With the addition of Gw3 filaments in addition of the curing the samples showed more ductile behavior and did not failed along any specific plane.

The suitability of the stabilized pond ash as highway sub grade material is determined by performing California Bearing Ratio Test (Photographic plate No.3.6) without any curing under unsoaked and soaked (4 days) conditions. The load penetration diagrams of the samples are presented in Fig.3.28 and Fig.3.29. The test results reveal considerable improvement in the performance of the material as using it in the subgrade. The improvements as measured by CBR value obtained by adding different admixtures are presented as follows:

i) Pond ash+Lime+Sodium chloride+ Fiber GW3:
25.45% (unsoaked), 19.85% (soaked)
ii) Pond ash+Lime+Sodium chloride
19.27% (unsoaked), 14.96% (soaked)
iii) Pond ash+Lime:
12.21% (unsoaked), 11.24% (soaked)

iv) Pond ash compacted at OMC:
7.88% (unsoaked), 7.54%(soaked)

Thus the maximum gains in CBR value is obtained by adding fibers along with chemicals over the same for compacted pond ash under similar conditions are 3.2 to 2.6 times respectively for unsoaked and soaked conditions.

As previously mainly unconfined compressive strength was used to evaluate the perfomace of the stabilized pond ash, triaxial tests (e.g. consolidated undrained test with pore water pressure measurement, drained test with volumetric change measurements) at various cell pressures were conducted. These are presented in figures 3.30 to 3.41. And the corresponding p-q. diagrams are

plotted in Figs 3.42 and 3.43. The test set up for the consolidated undrained test is shown in Photographic plate No.3.7

From Figs. 3.30 (CU Test), 3.31 (CD Test) the tangent modulus values of secant modulus and initial tangent modulus are estimated. Secant modulus is obtained by taking the ratio of the difference between the stress values corresponding to the 50% failure strain and the initial stress to the 50% strain value. The estimated values are presented in Table 3.3. It can be observed form the table that the increase in the secant and initial tangent modulus values adding Garlon-GW3 is maximal. And the samples with Garlon-NW2 showed higher moduli values than those for samples with nylon threads.

In tables 3.4 and 3.5 are shown the relative increase in strength of the pond ash samples prepared with different admixtures. Table 3.4 shows that the maximum increase in strength represented by the Effective stress modulus of elasticity of samples with optimum content of fibers, lime and sodium chloride is 2.5 times to 4 times under undrained and drained conditions respectively in comparison to that of compacted pond ash with out any admixture. With nylon threads the corresponding values are the least the values being 1.8 and 1.5 respectively at 350 kPa cell pressure. For 100kPa the corresponding values are 1.22 and 1.47 respectively. Taking the moduli values of the compacted pond ash samples as the base the corresponding percentage increment due to the admixtures are calculated and presented in Table 3.5. It can be seen that the maximum percentage increase in the moduli values (162 %) is for Garlon-GW3 threads the minimum value (37.5%) is for nylon threads at 350kPa.

Pore pressure response diagrams corresponding to 350 and 200 Kpa cell pressure (Fig 3.34 and fig 3.35) under CU test show that substantial reduction in the pore pressure values with strain with addition of fibers in comparison to compacted and stabilized pond ash. For CD test the volumetric strain with axial strain (Fig 3.36, 3.37) for 350 and 200 Kpa cell pressure show maximum volumetric strain is obtained with sodium chloride additives. Similar behavior is observed (Fig 3.41) for 100 Kpa cell pressure.

The effective stress shear strength parameters as computed from figures 3.42 and 3.43 are presented in Table 3.6. It can be seen from the figure that different stabilization process improves the values of the strength parameters significantly. The effect of stabilization is more pronounced in changing the effective cohesion values. Increase in the values (from 34° to 41°) of effective friction angle also occurs especially when the pond ash is stabilized with lime, sodium chloride and Garlon-GW3 fibers in comparison to the corresponding value (34°) when only the above chemicals are used for stabilization with out adding any fiber filaments. The percentage increase in the effective stress strength parameters adding different admixtures to the Panki pond ash with respect to the same for compacted pond ash is presented in Table 3.7. It can be seen that depending on the cell

pressure value and the drainage condition the range of increment in the effective stress strength parameters is maximum for Samples stabilized with chemicals and Garlon-GW3 the value being 1777% to 1846%

TABLE 3.3: Modulus of elasticity values of pond ash stabilized with different admixture: (kPa)

	Cell pressure = 350 Kpa				Cell pressure = 200 Kpa				Cell pressure = 100 Kpa			
	CU Test E_s	CD Test E_s	CU Test E_{ti}	CD Test E_{ti}	CU Test E_s	CD Test E_s	CU Test E_{ti}	CD Test E_{ti}	CU Test E_s	CD Test E_s	CU Test E_{ti}	CD Test E_{ti}
FA	15100	15600	12200	19600	13020	13300	12000	19040	10980	11000	10030	12100
OLC	19405	25500	16676	26300	16311	19003	15150	21000	12032	14050	11360	14900
Nacl (opt)	21333	29226	21251	29582	18666	21000	17045	22300	14020	16000	12000	17050
Garlon. GW.3	40304	66412	28294	44000	25666	31500	24500	32736	18666	19552	14333	20411
Garlon NW.2	28800	30520	23455	39200	22422	24000	21020	24222	16044	17200	12523	17900
Nylon Rope	24000	29300	21800	32020	20333	23200	20200	23666	15100	16100	12300	17880

TABLE.3.4: Ratio of increment in moduli values with respect to compacted pond Ash

	Cell pressure = 350 Kpa		Cell pressure = 200 Kpa		Cell pressure = 100 Kpa	
	CU Test	CD Test	CU Test	CD Test	CU Test	CD Test
OLC	1.28	1.63	1.25	1.42	1.09	1.23
Nacl (opt)	1.41	1.87	1.44	1.57	1.19	1.40
Garlon.G w.3	2.66	4.03	2.97	2.36	2.42	2.68
Garlon Nw.2	1.90	1.95	1.72	1.86	1.24	1.49
Nylon rope	1.58	1.87	1.56	1.74	1.22	1.47

TABLE 3.5: Pencentage increment in the moduli values of stabilized pond ash with respect to compacted pond ash

	Cell pressure = 350 Kpa		Cell pressure = 200 Kpa		Cell pressure = 100 Kpa	
	CU Test	CD Test	CU Test	CD Test	CU Test	CD Test
FA	0	0	0	0	0	0
OLC	26.55	58.30	25.13	45.5	9.24	25.72
Nacl (opt)	36.78	81.5	31.13	72.9	27.50	45.45
Garlon. Gw.3	146.77	163.44	97.8	140.4	70.01	77.77
Garlon Nw.2	84.74	89.56	61.5	80.8	45.21	60.4
Nylon rope	64.95	85.15	56.4	74.6	37.52	53.7

TABLE 3.6: Effective stress strength parameters of stabilized Panki pond ash

	CU Test		CD Test	
	C^1(Kpa)	Φ^1(Degree)	C^1 (Kpa)	Φ^1(Degree)
OMC + FA	12.15	30	13.01	31
OMC +OLC + FA	71.54	32	78.56	33
OMC +OLC + Nacl (opt) + FA	124.5	33	147.39	34
OMC +OLC + Nacl (opt) + GW.3 + FA	220.8	38	253.80	41
OMC +OLC + Nacl (opt) + NW.3 + FA	166.93	36	183.8	37
OMC +OLC + Nacl (opt) + Nylon Rope + FA	130.2	34	150.5	35

TABLE 3.7: Pencentage increment in effective stress strength parameters of stabilized Panki pond ash

	CU Test		CD Test	
	C^1(Kpa)	Φ^1(Degree)	C^1 (Kpa)	Φ^1(Degree)
OMC + FA	0	0	0	0
OMC +OLC + FA	488.8	6.6	504	6
OMC +OLC + Nacl (opt) + FA	924.24	10	1030	9
OMC +OLC + Nacl (opt) + GW.3 + FA	1717	26.6	1846	32
OMC +OLC + Nacl (opt) + NW.3 + FA	1273	20	1307	19
OMC +OLC + Nacl (opt) + Nylon Rope + FA	971	13	1053	12

RESULTS OF SEM ANALYSIS:

FIGURES OF THE EXPERIMENTAL STUDY CONDUCTED ON PANKI POND ASH WITH RANDOMLY ORIENTED GEOTEXTILE FILAMENTS:

PLATE.NO. 2.1

Fly ash particles orientation:

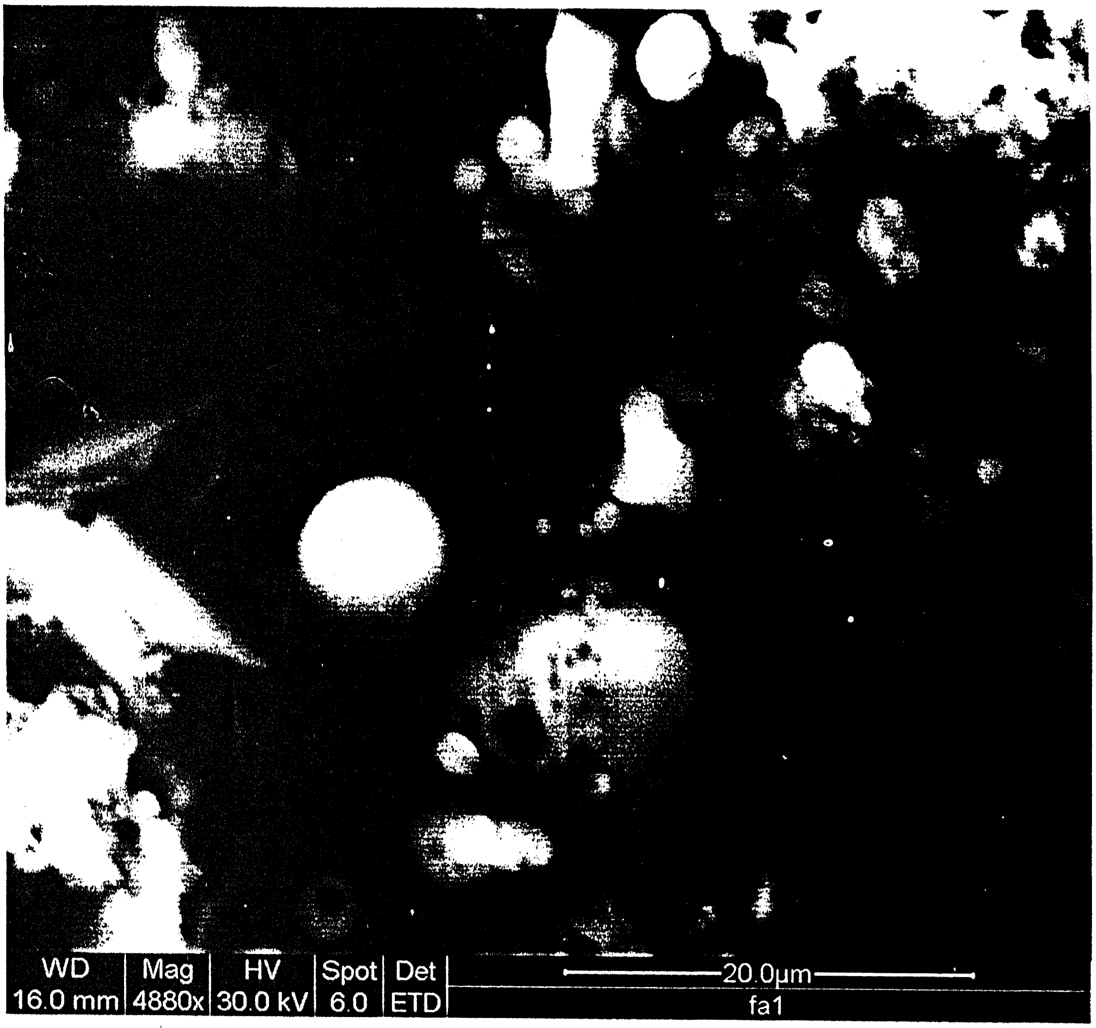


PLATE.NO.2.2

Fly ash particles orientation: single fly ash particle:

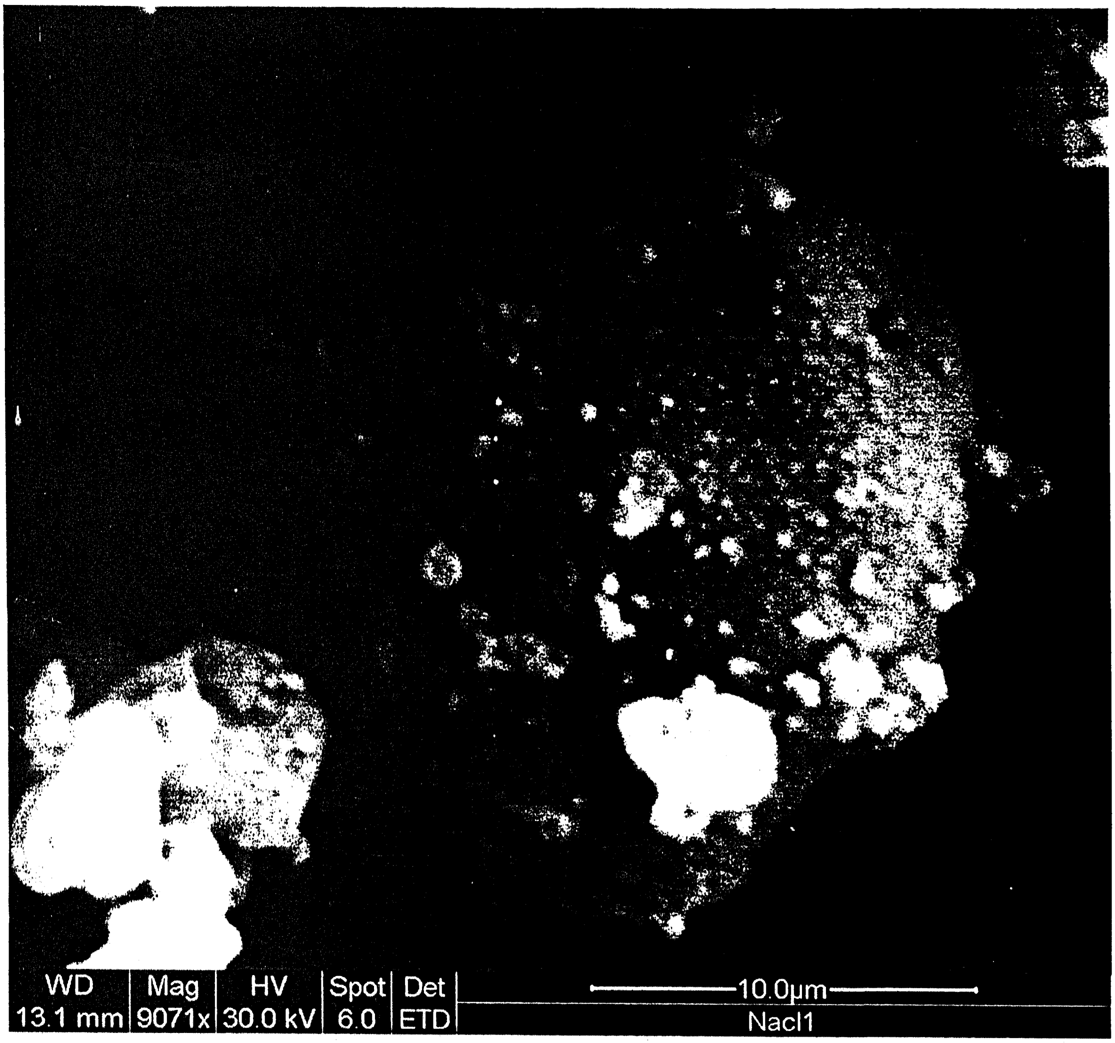


PLATE.NO. 3.1

Fly ash particles orientation mixed with optimum lime content:

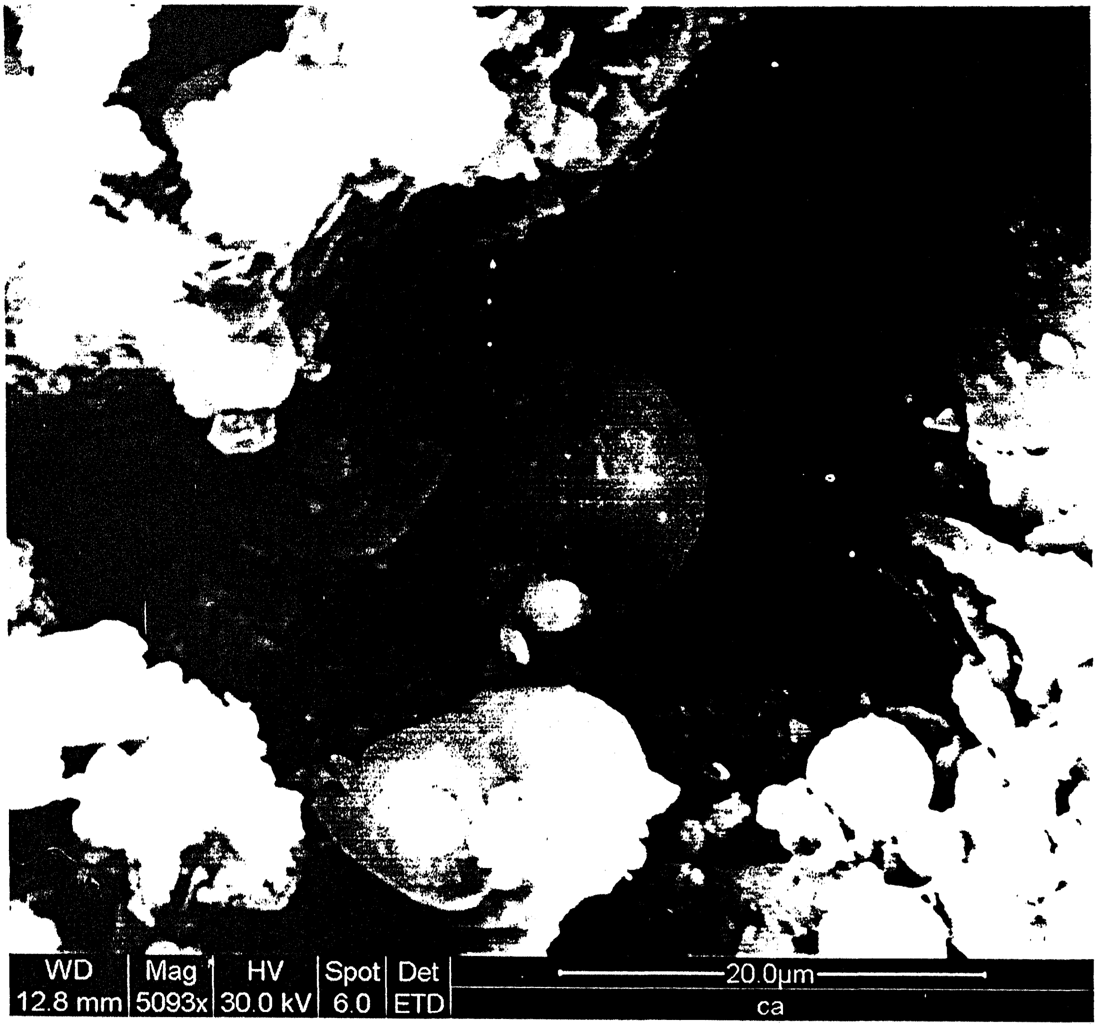


PLATE.NO. 3.2

Fly ash particles orientation mixed with optimum lime content:

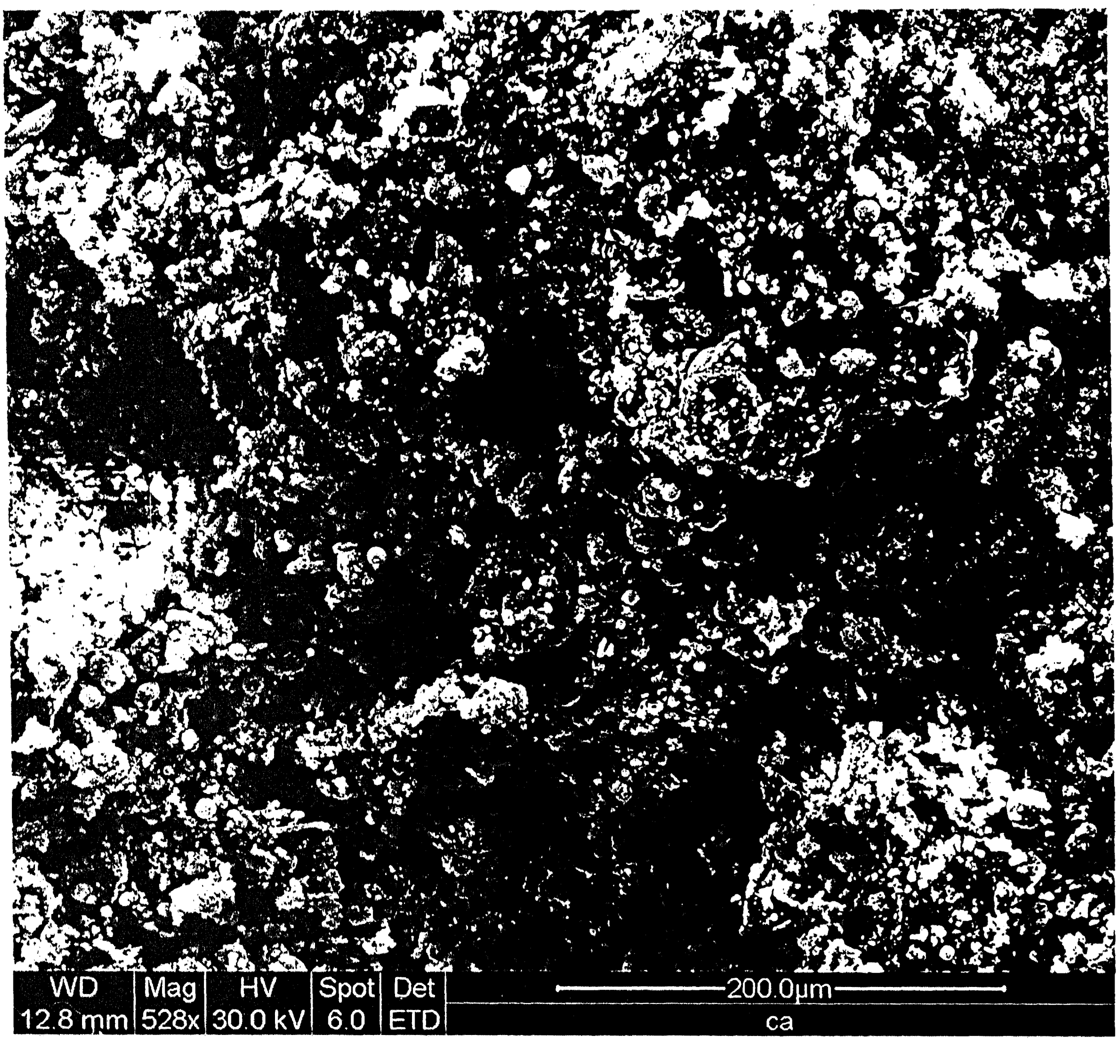


PLATE.NO. 3.3

Fly ash particles orientation mixed with optimum lime content and optimum sodium chloride:

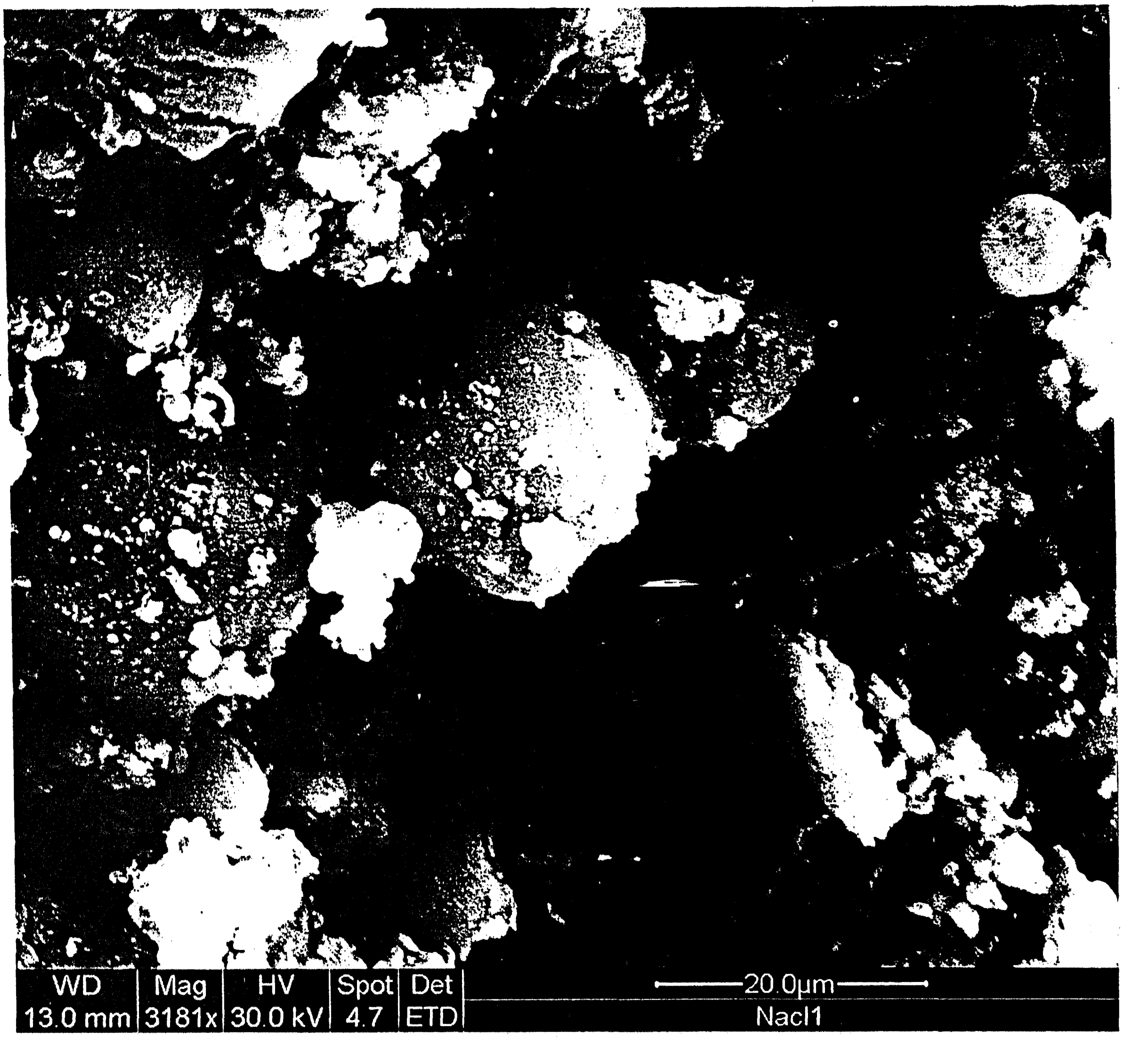


PLATE.NO.3.4

Fly ash particles orientation mixed with optimum lime content and optimum sodium chloride:

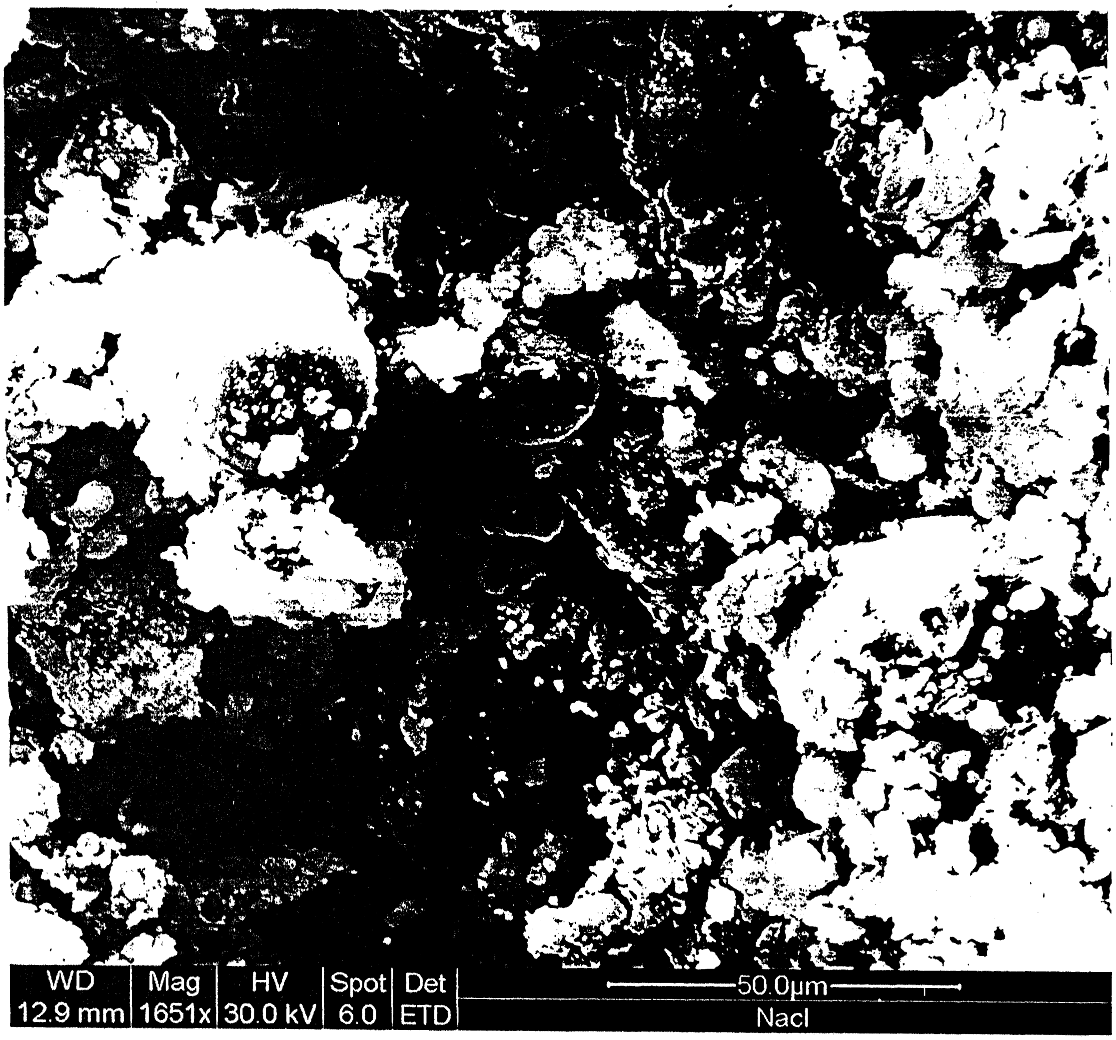


PLATE.NO. 3.5

Fly ash particles orientation mixed with optimum lime content and optimum sodium chloride:

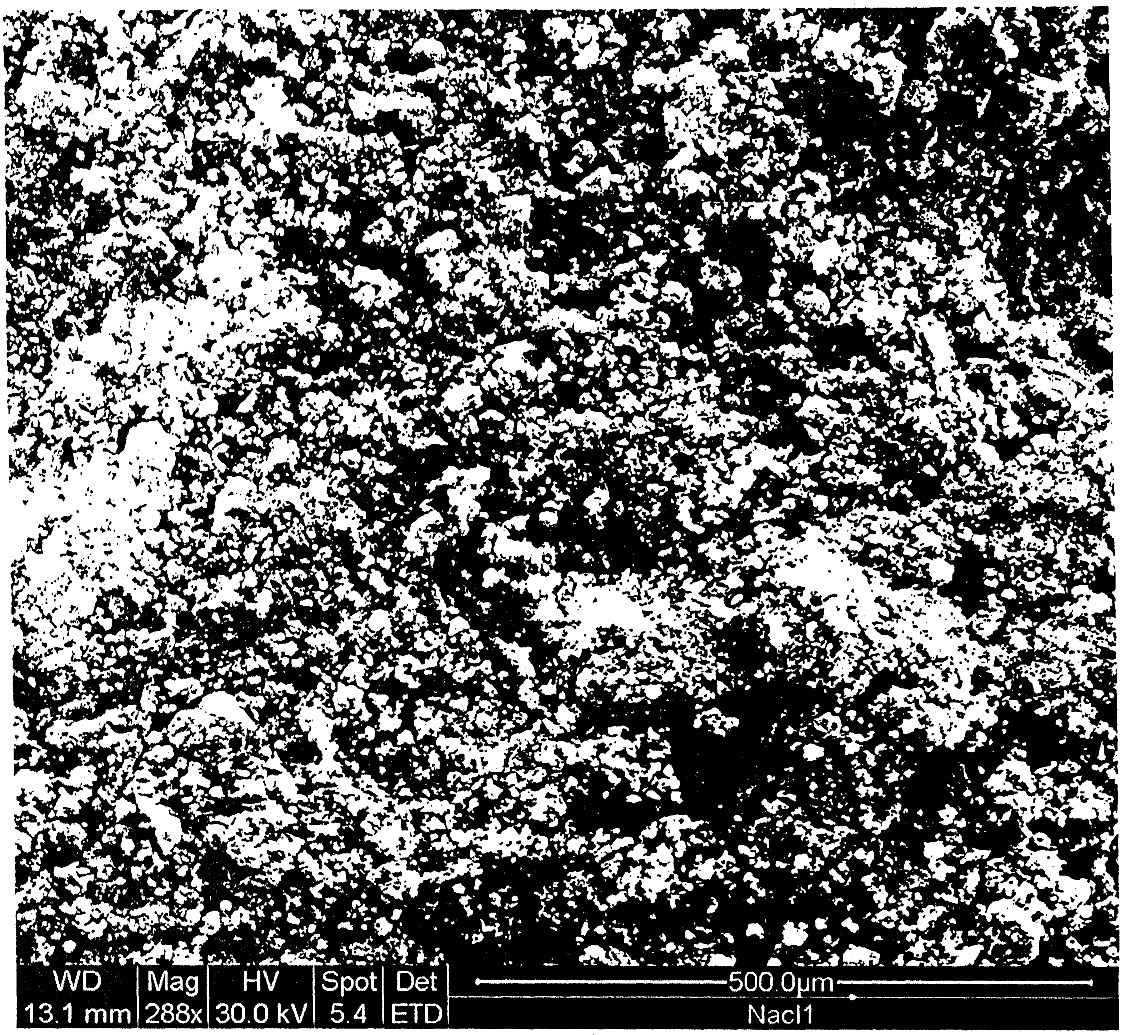
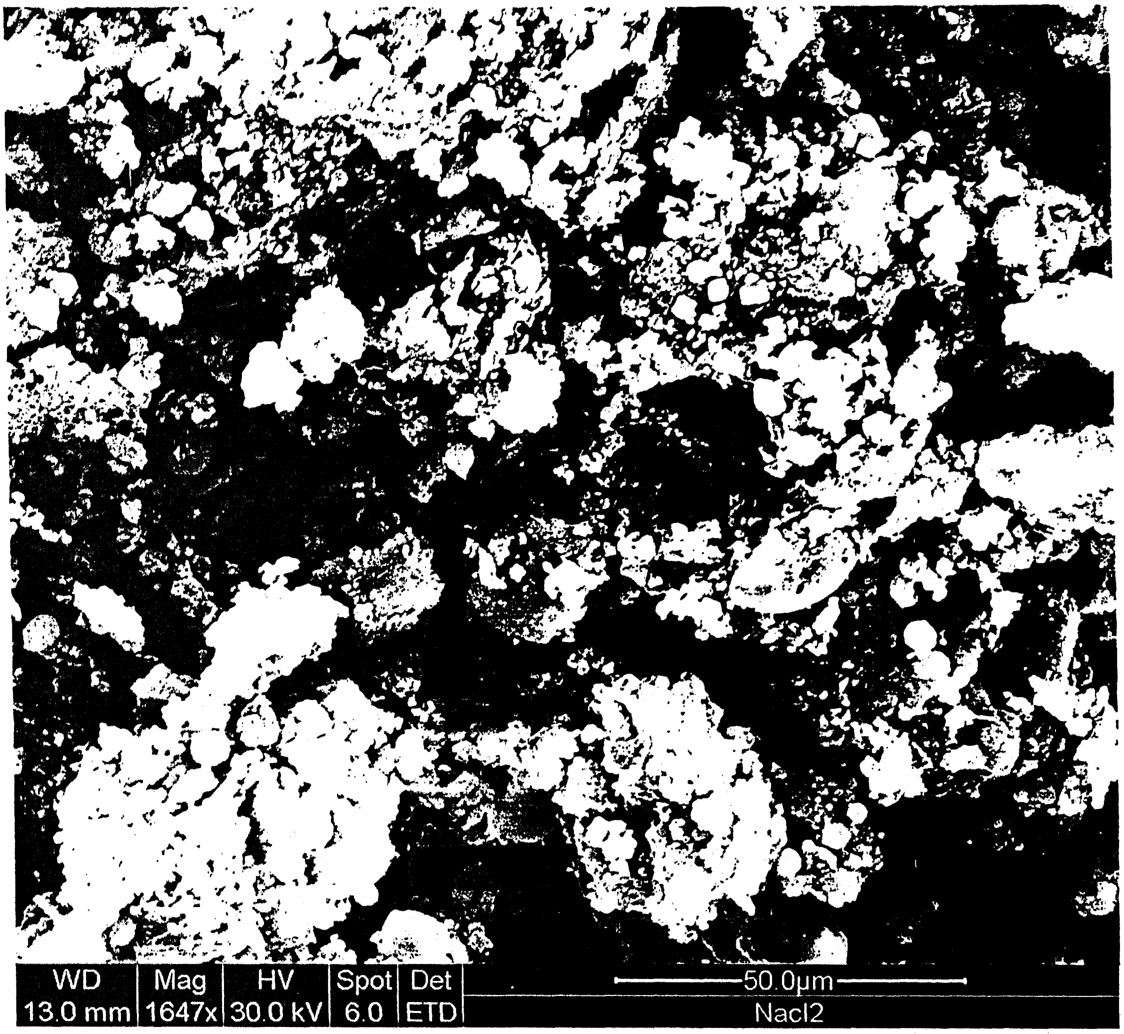


PLATE.NO. 3.6
Fly ash particles orientation mixed with optimum lime content and optimum sodium chloride



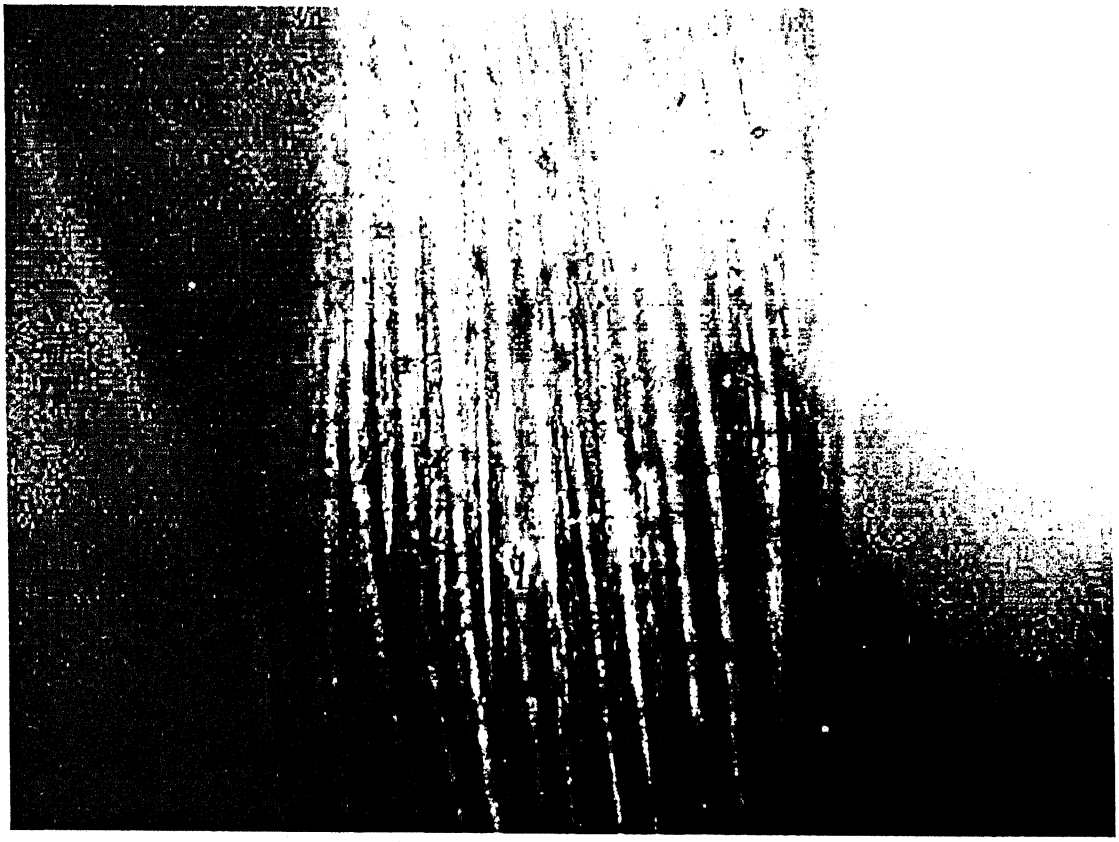
RESULTS OF THE OPTICAL MICROSCOPIC STUDY:

ORINENTATION OF FIBER FILAMETS USED IN THE PRESENT STUDY:

PLATE.NO. 3.7

GARLON –GW3: POLYPROPELENE GEOTEXTILE FILAMENT:

FIGURE NO. 3.8



GARLON –NW2: POLYPROPELENE GEOTEXTILE FILAMENT:

FIGURE NO. 3.9

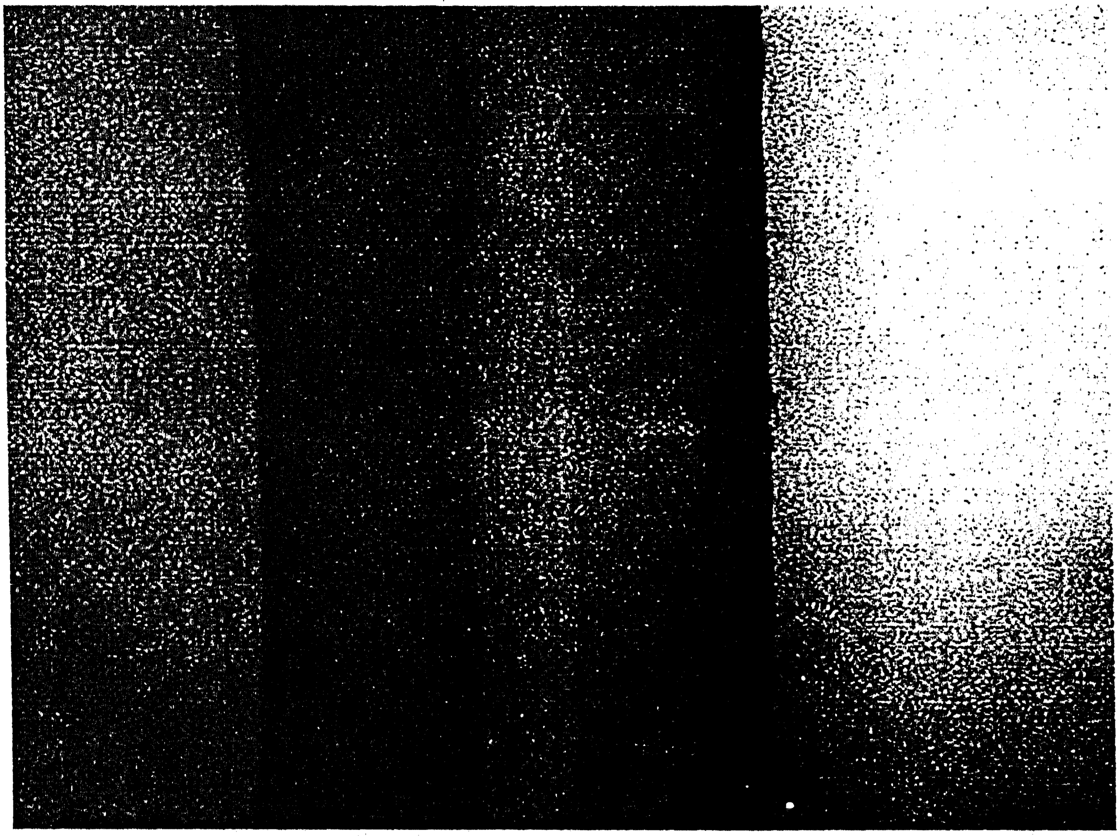
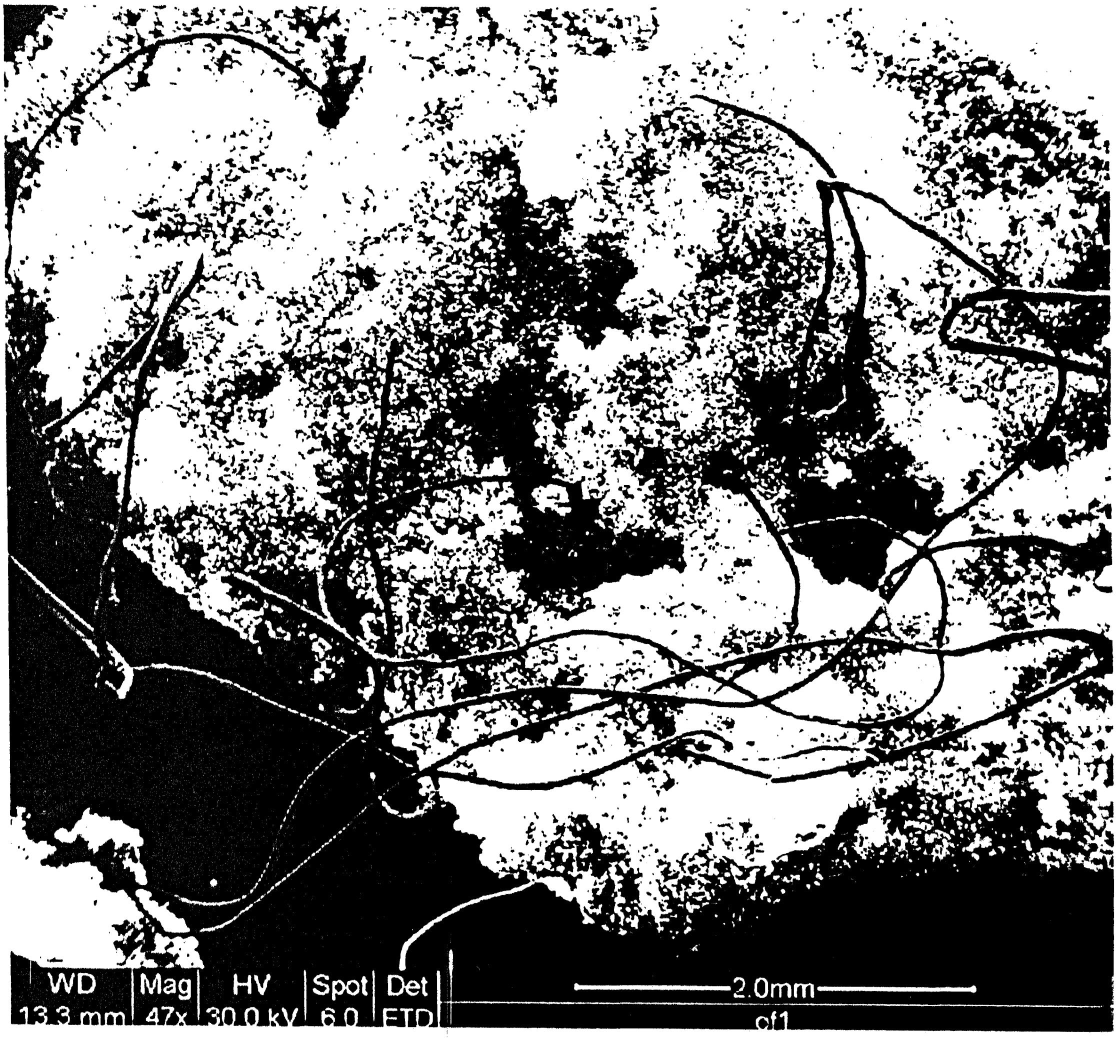
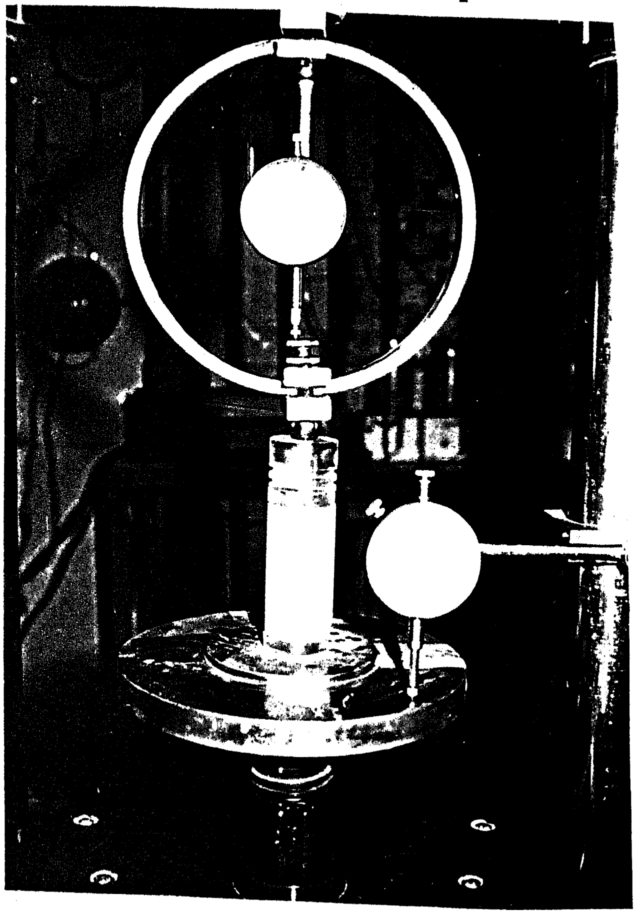


IMAGE OF THE NYLON ROPE:

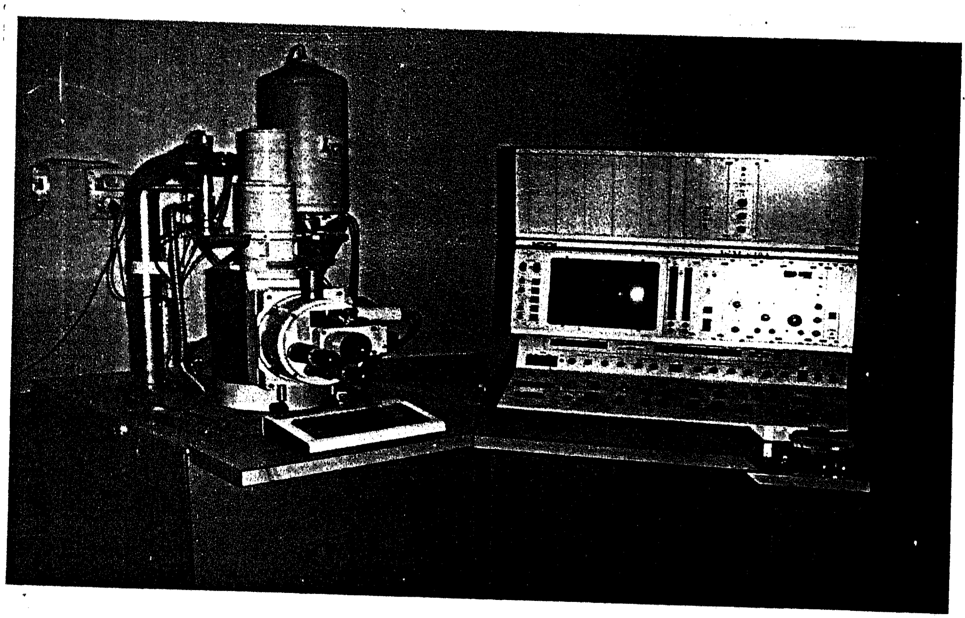
PLATE.NO. 3.10
Fly ash particles orientation mixed with optimum lime content and optimum sodium chloride plus optimum fiber content (garlon-1):



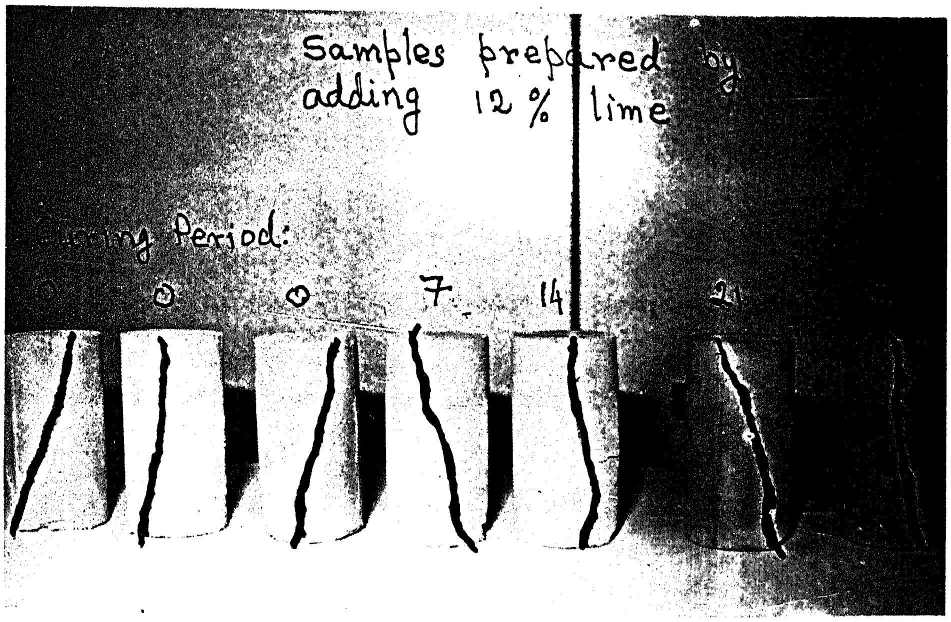
Photographic Plate No.3.1 Unconfined Compression test set-up



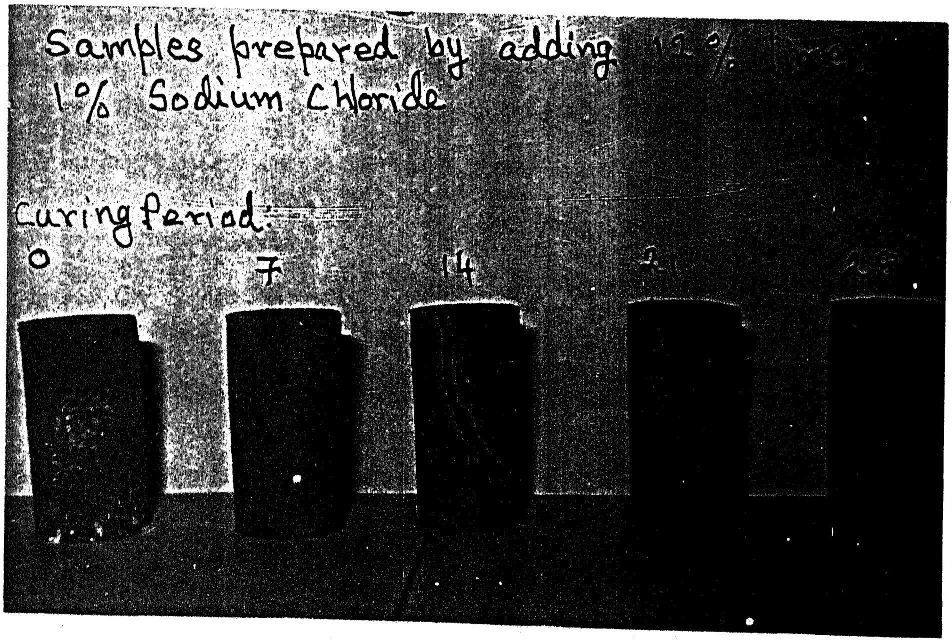
Photographic Plate No.3.2 Scanning Electron Microscopic device



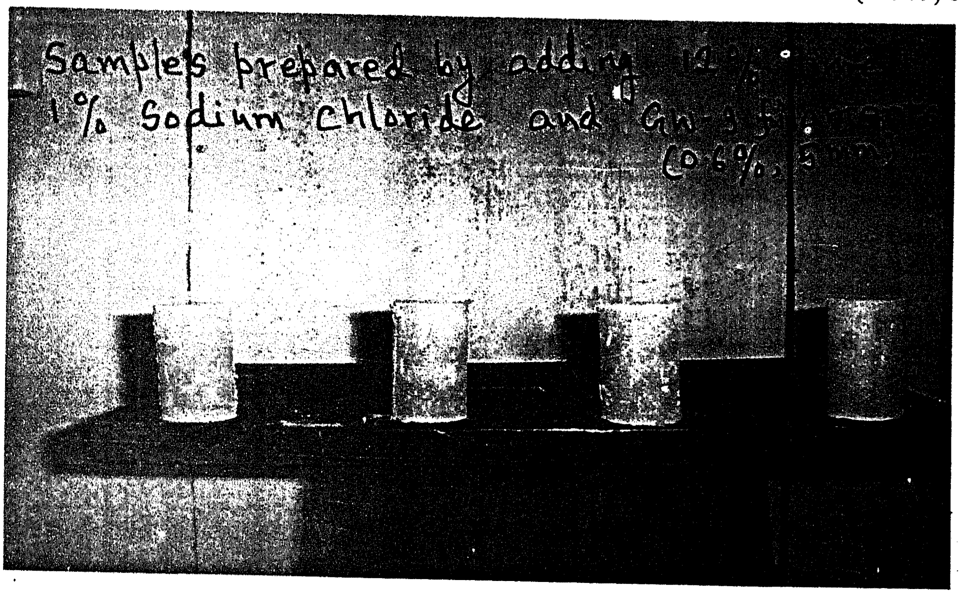
Photographic Plate No.3.3 Failure planes of samples prepared by adding 12 % Lime



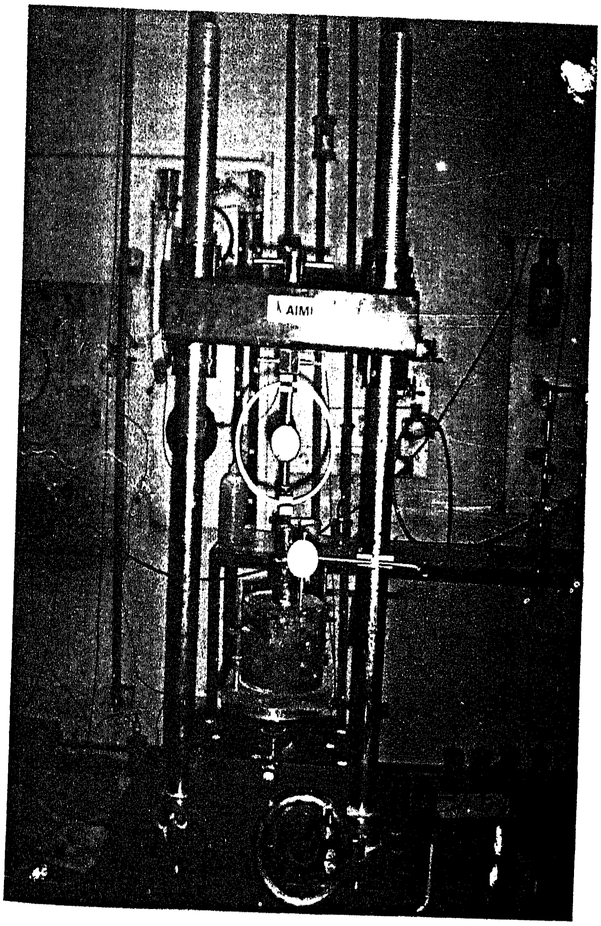
Photographic Plate No.3.4 Failure planes of samples prepared by adding 12 % Lime, 1% sodium chloride



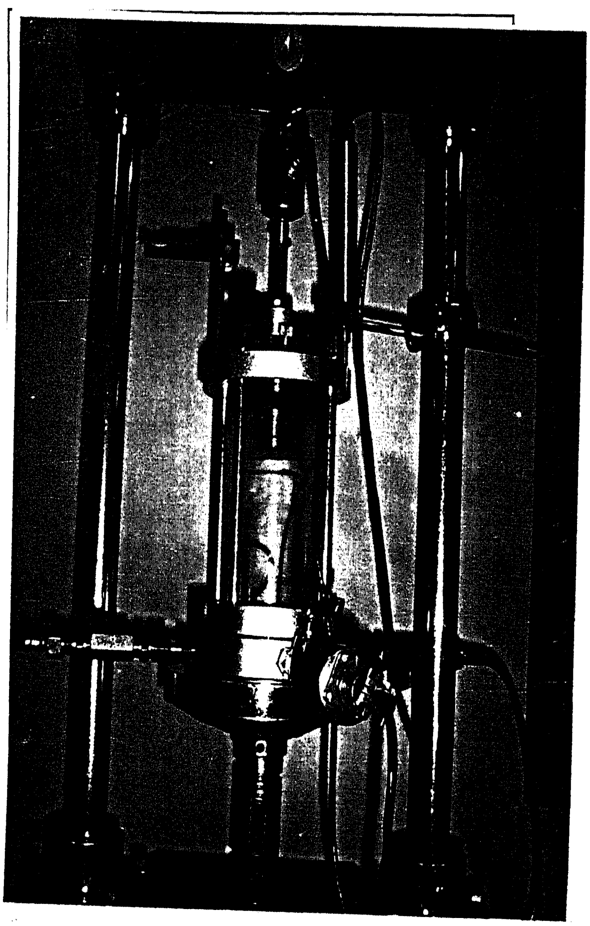
Photographic Plate No.3.5 Failure planes of samples prepared by adding 12 % Lime, 1% sodium chloride and GW3 filaments (0.6%, 5mm)



Photographic Plate No.3.6
CBR Test set-up



Photographic Plate No.3.7
Triaxial Test set-up



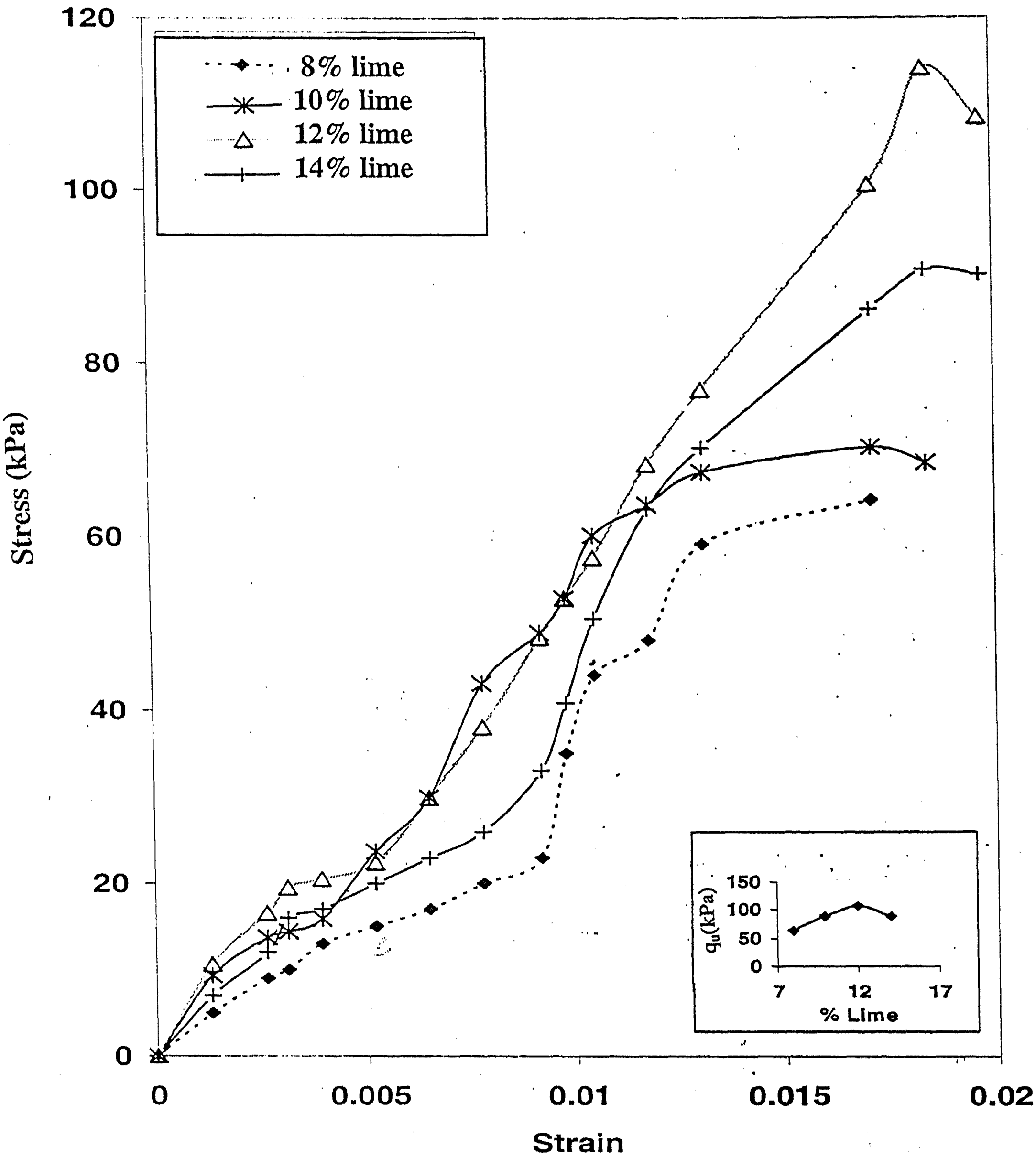


Fig. 3.1 Determination of optimum lime content

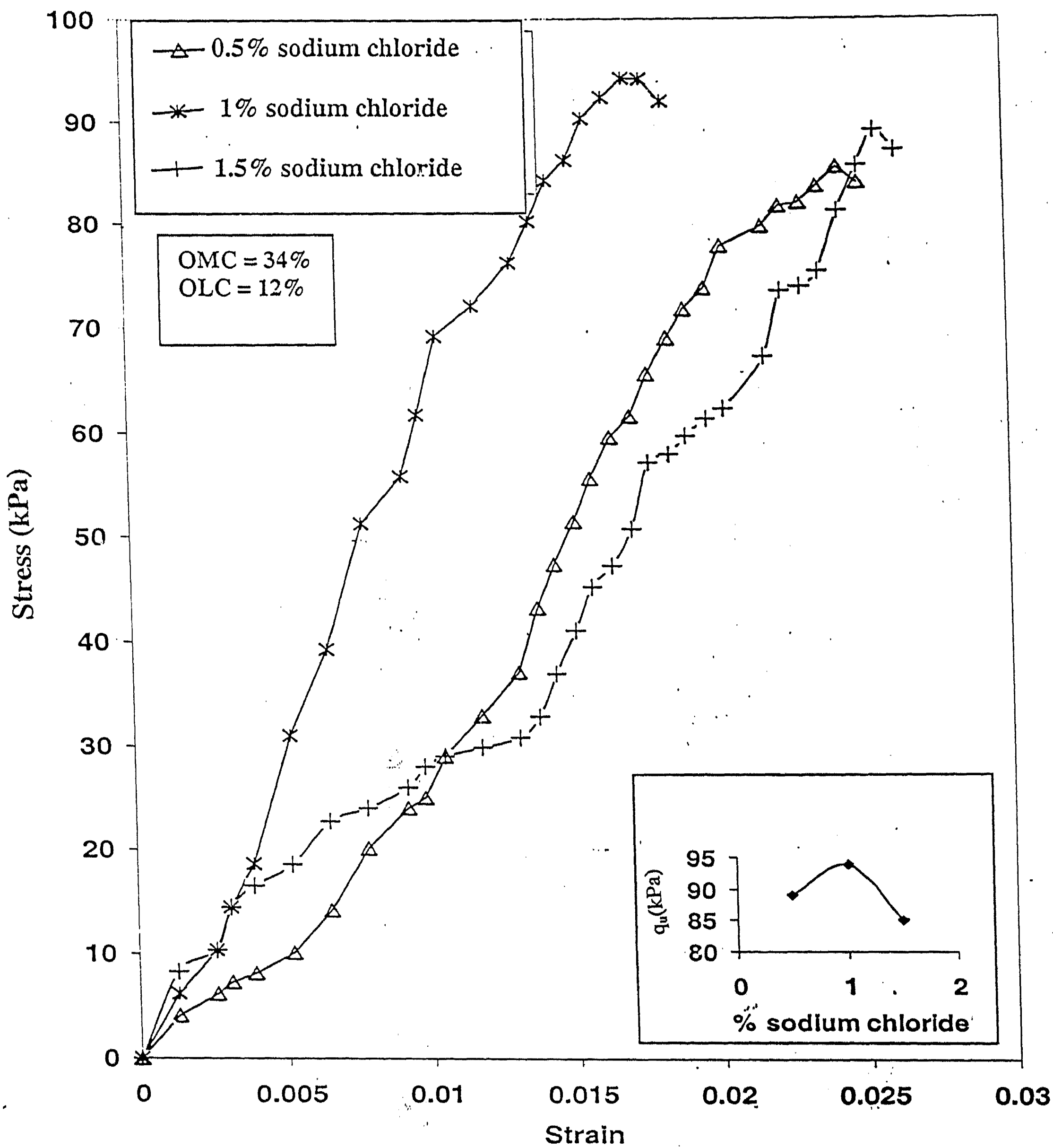


Fig. 3.2 Determination of optimum sodium chloride content

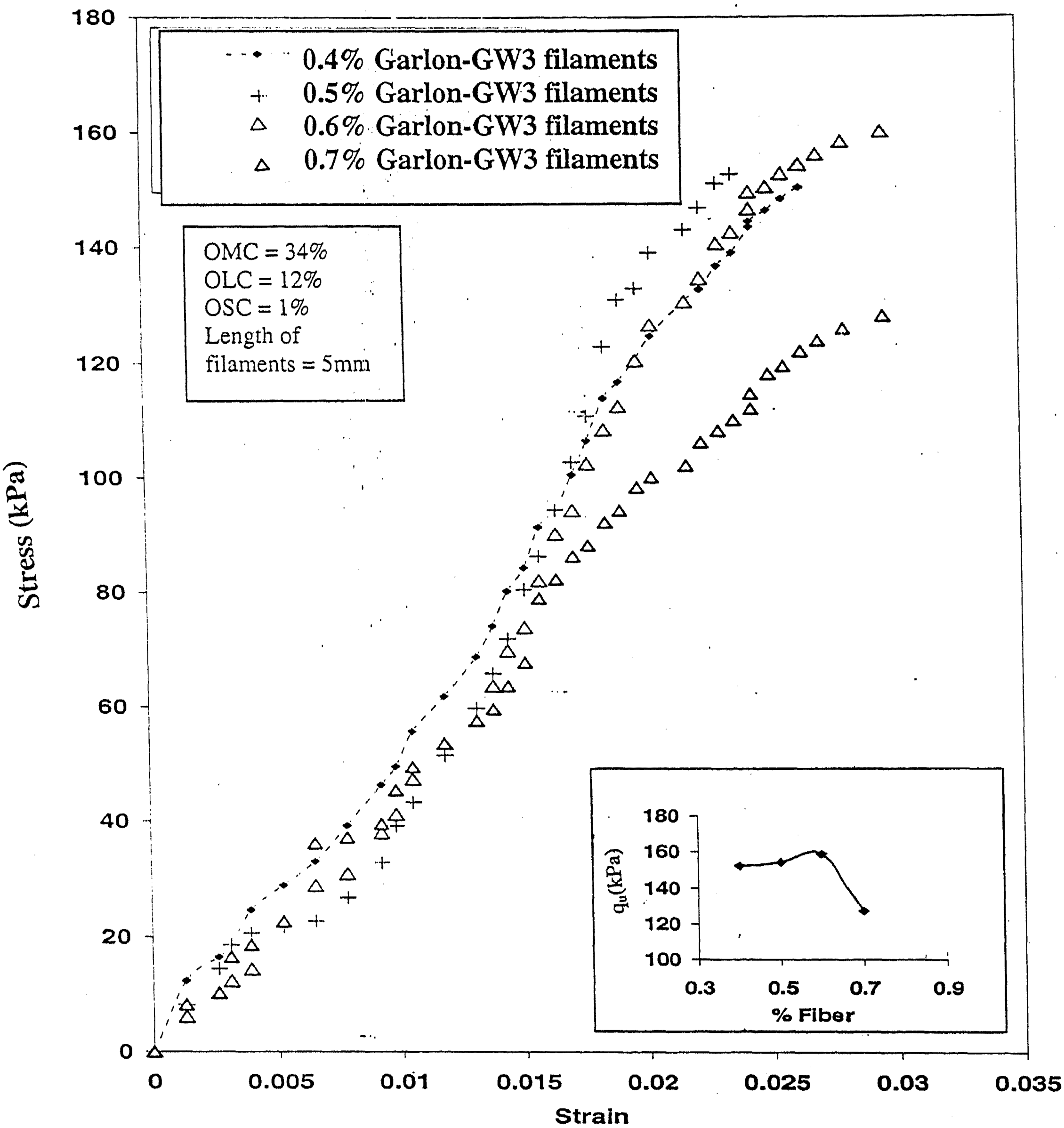


Fig. 3.3 Determination of optimum fiber content

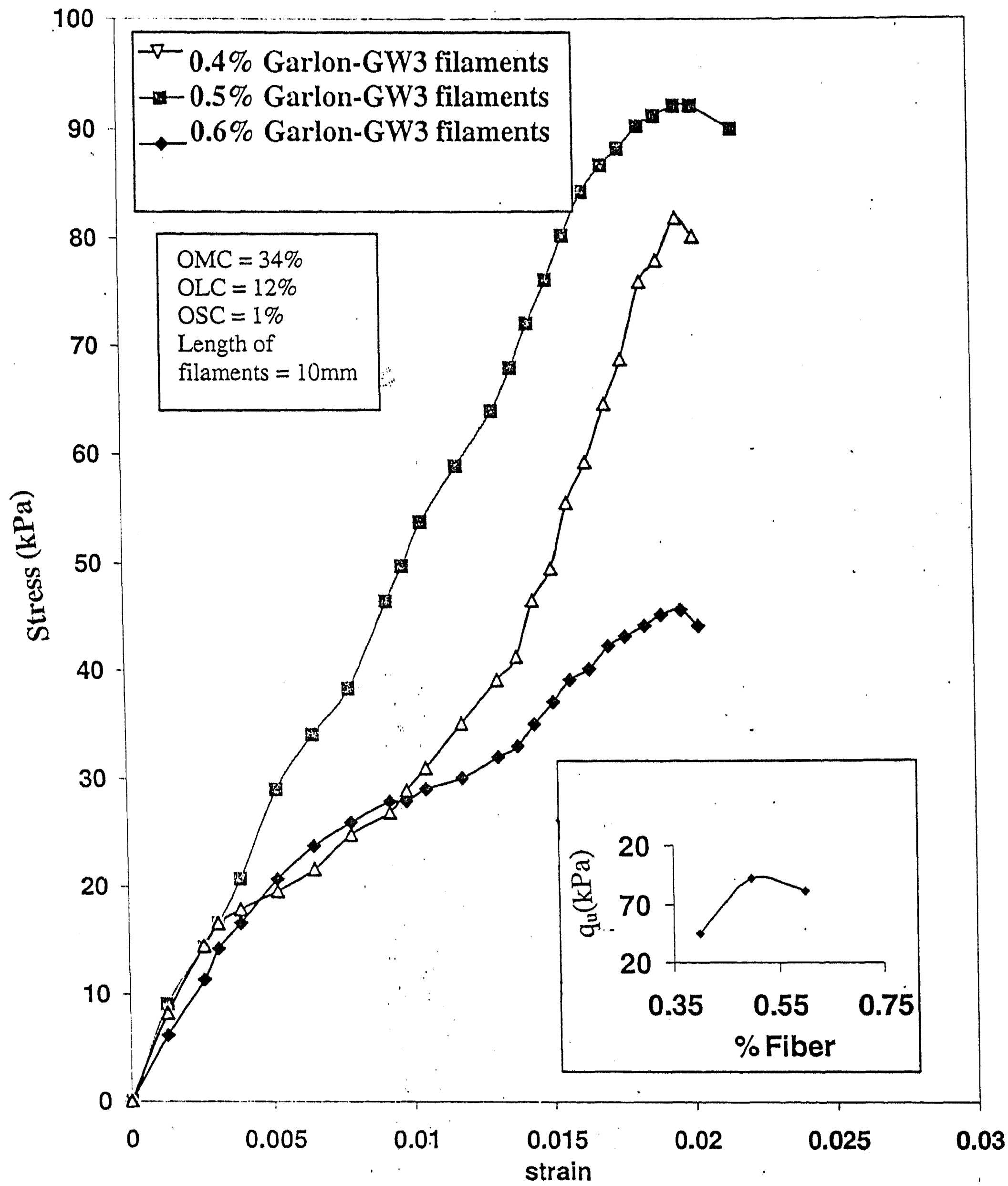


Fig. 3.4 Determination of optimum fiber content

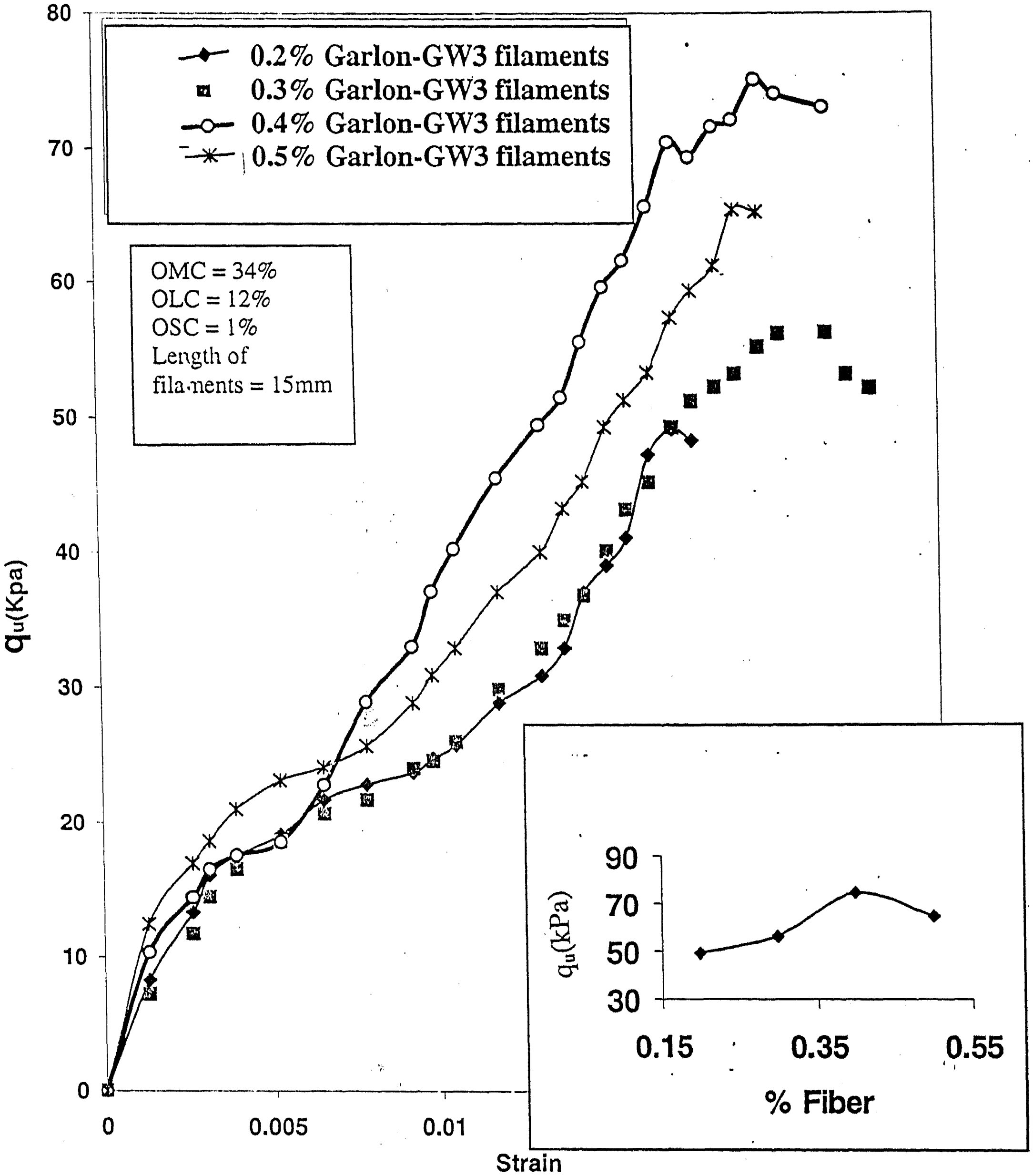


Fig. 3.5 Determination of optimum fiber content

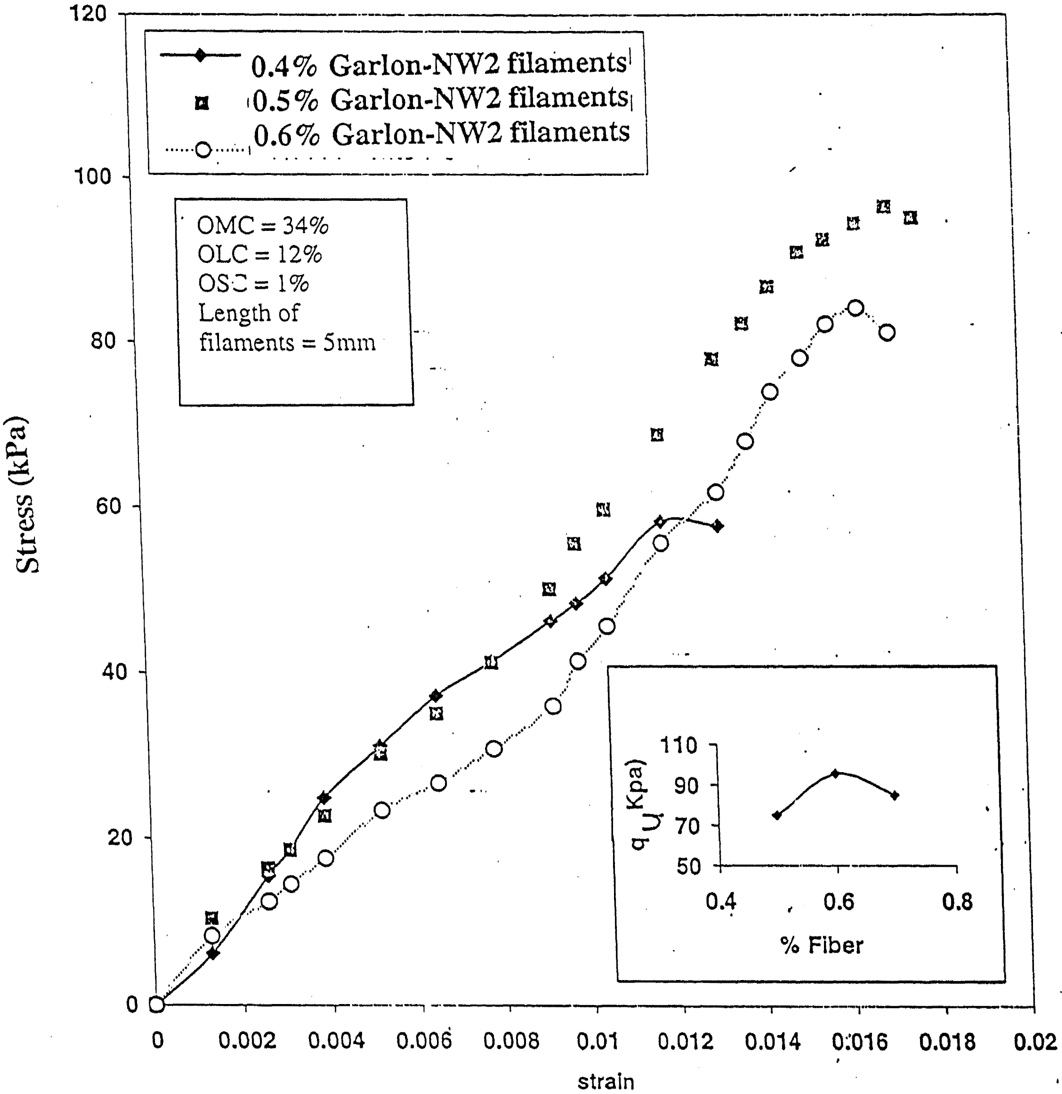


Fig. 3.6. Determination of optimum fiber content

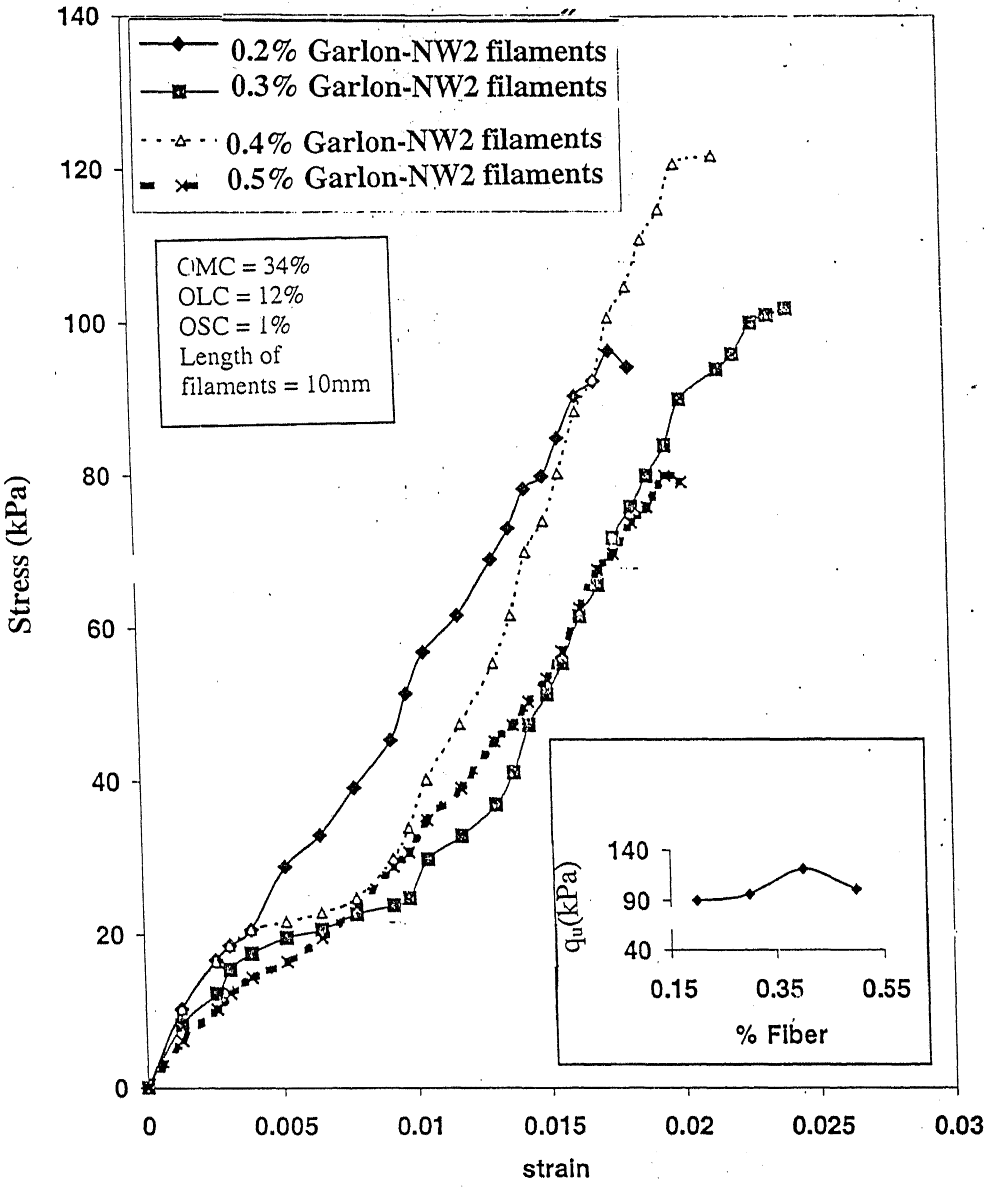


Fig. 3.7 Determination of optimum fiber content

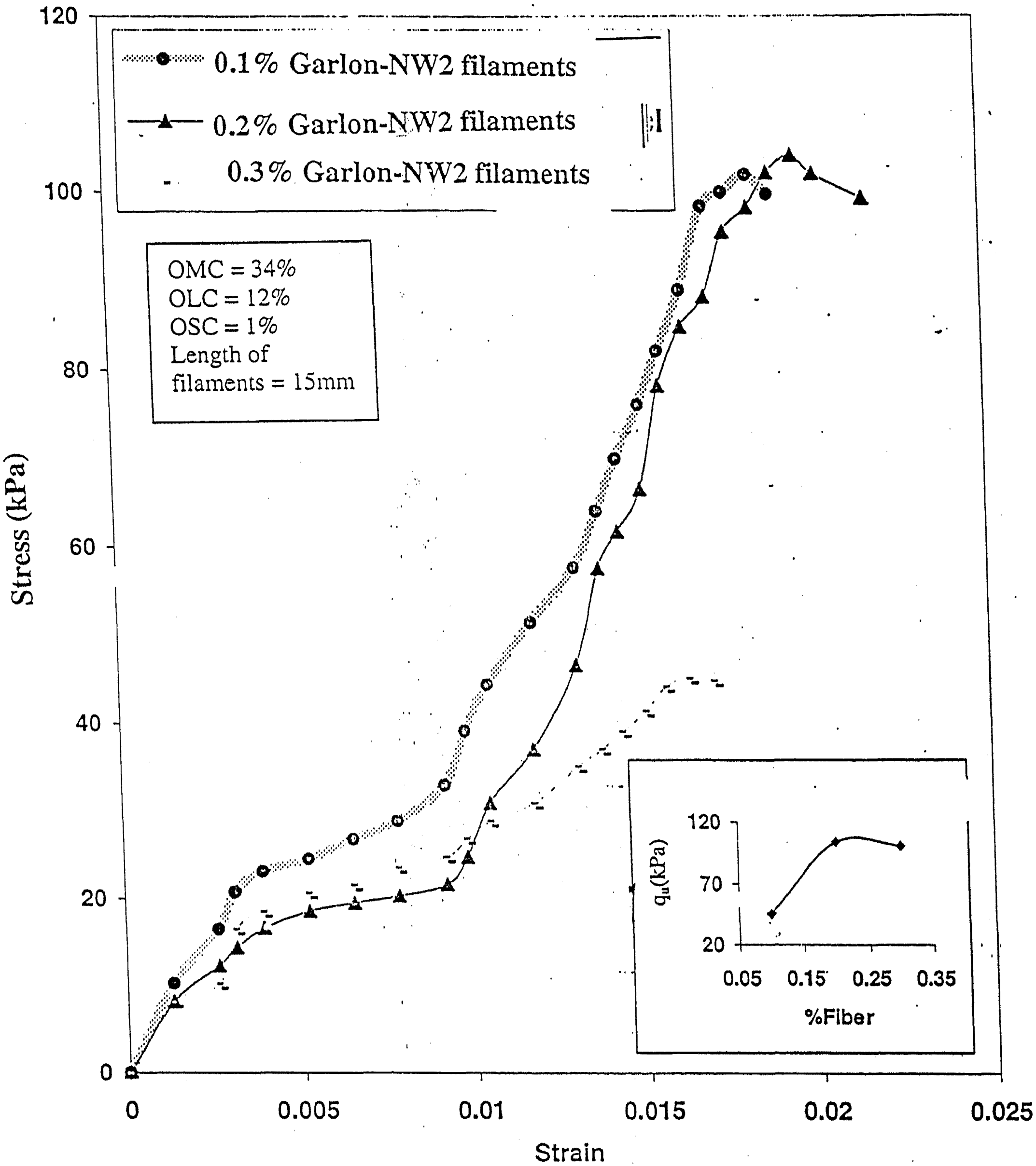


Fig. 3.8 Determination of optimum fiber content

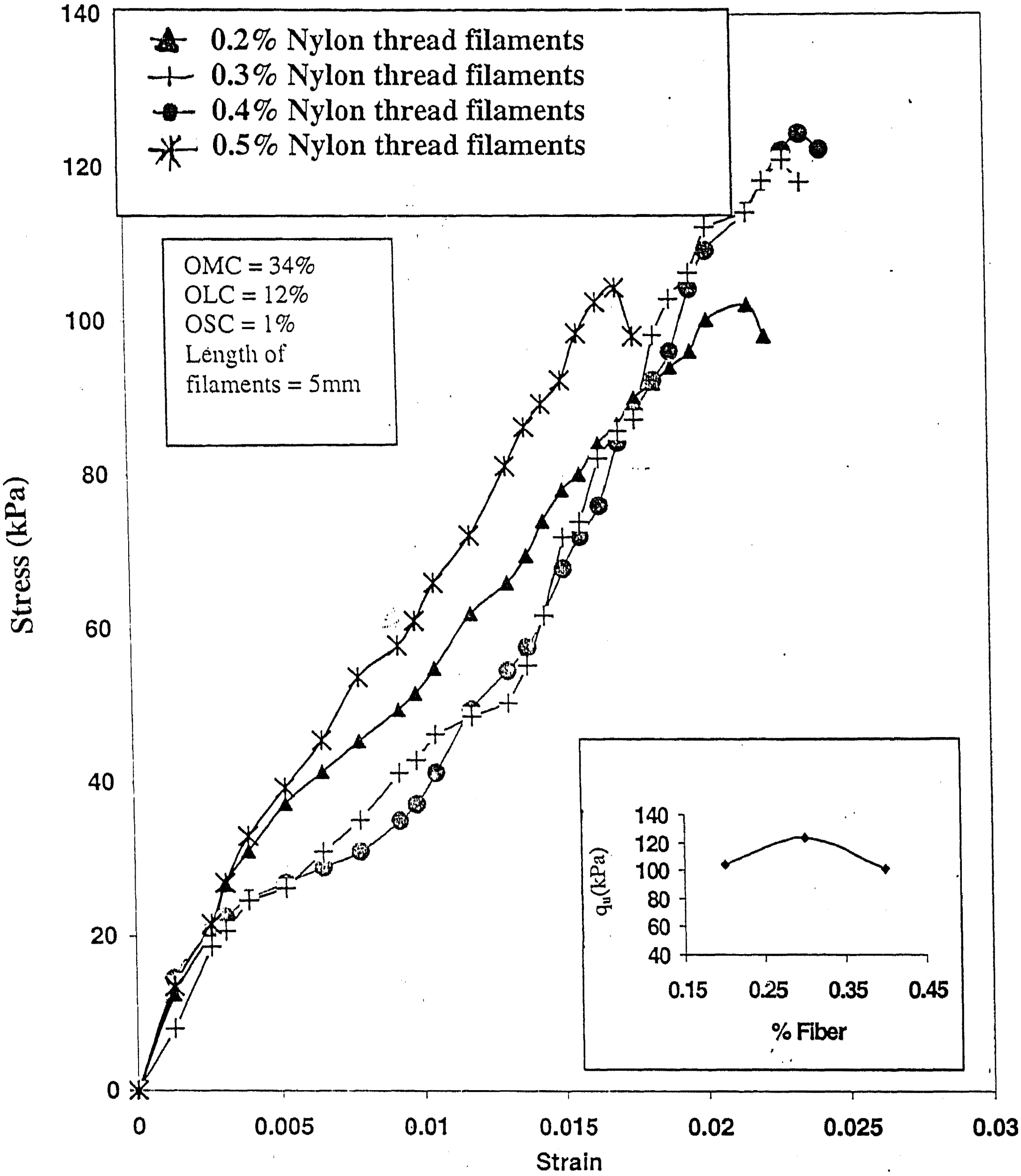


Fig. 3.9 Determination of optimum fiber content

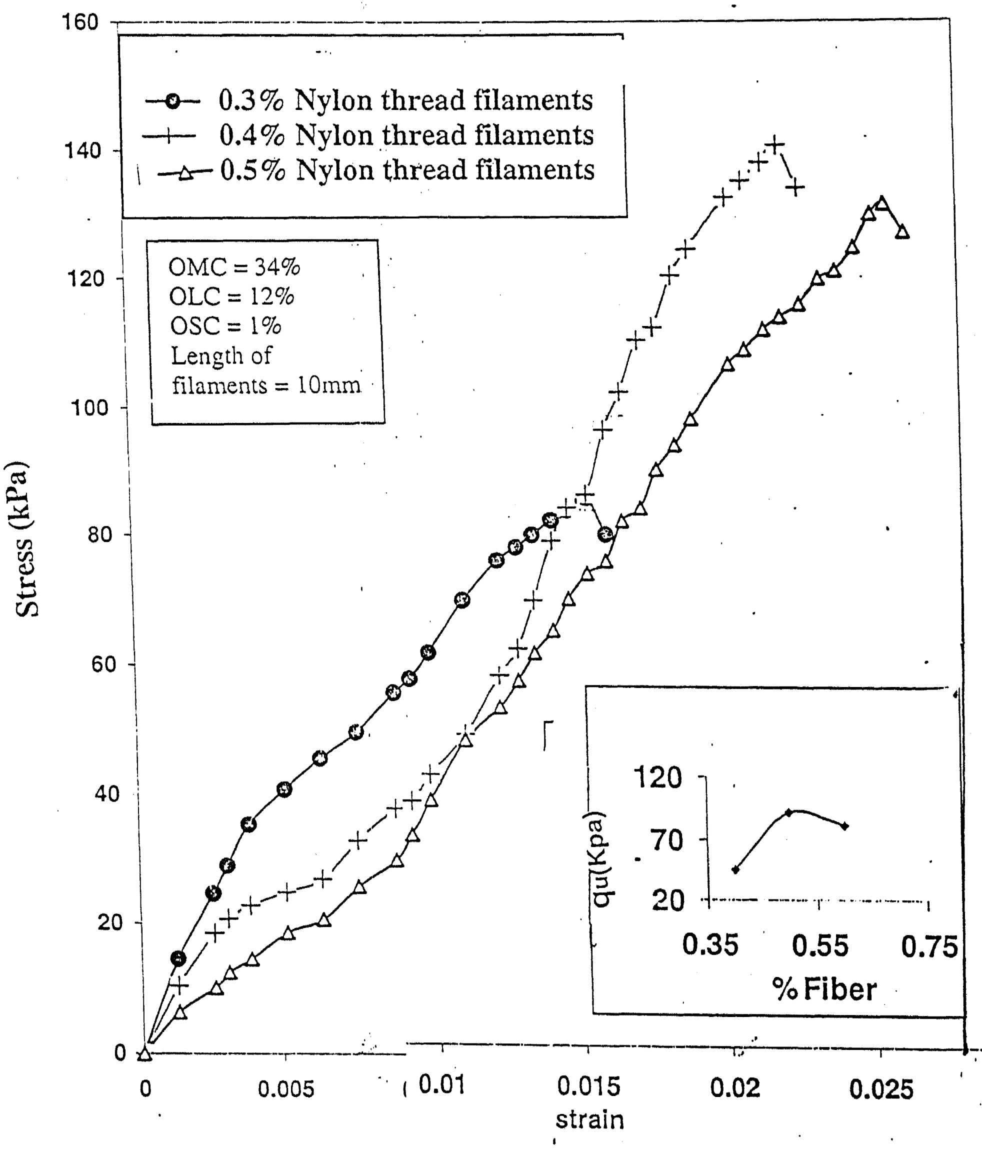


Fig. 3.10 Determination of optimum fiber content

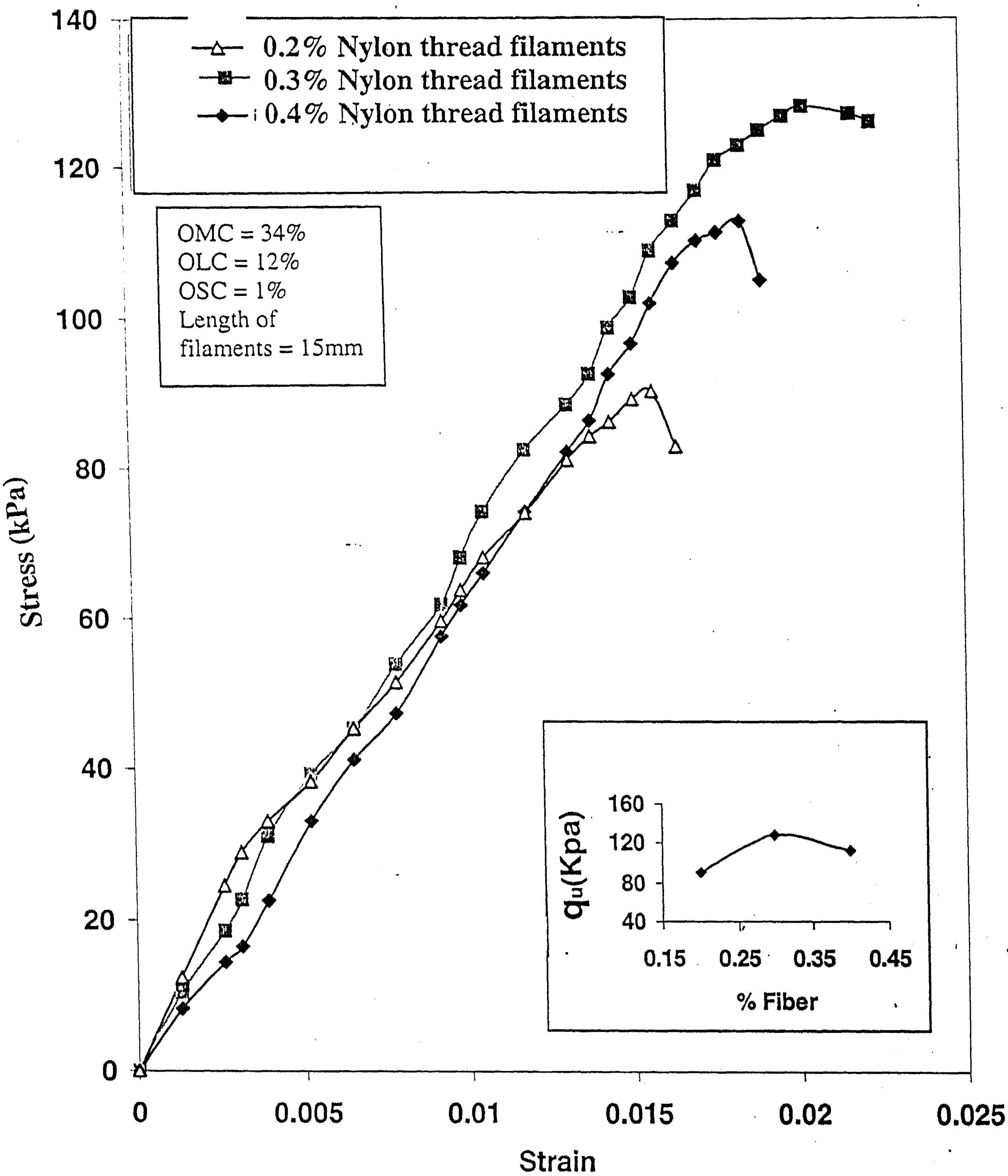


Fig. 3.11 Determination of optimum fiber content

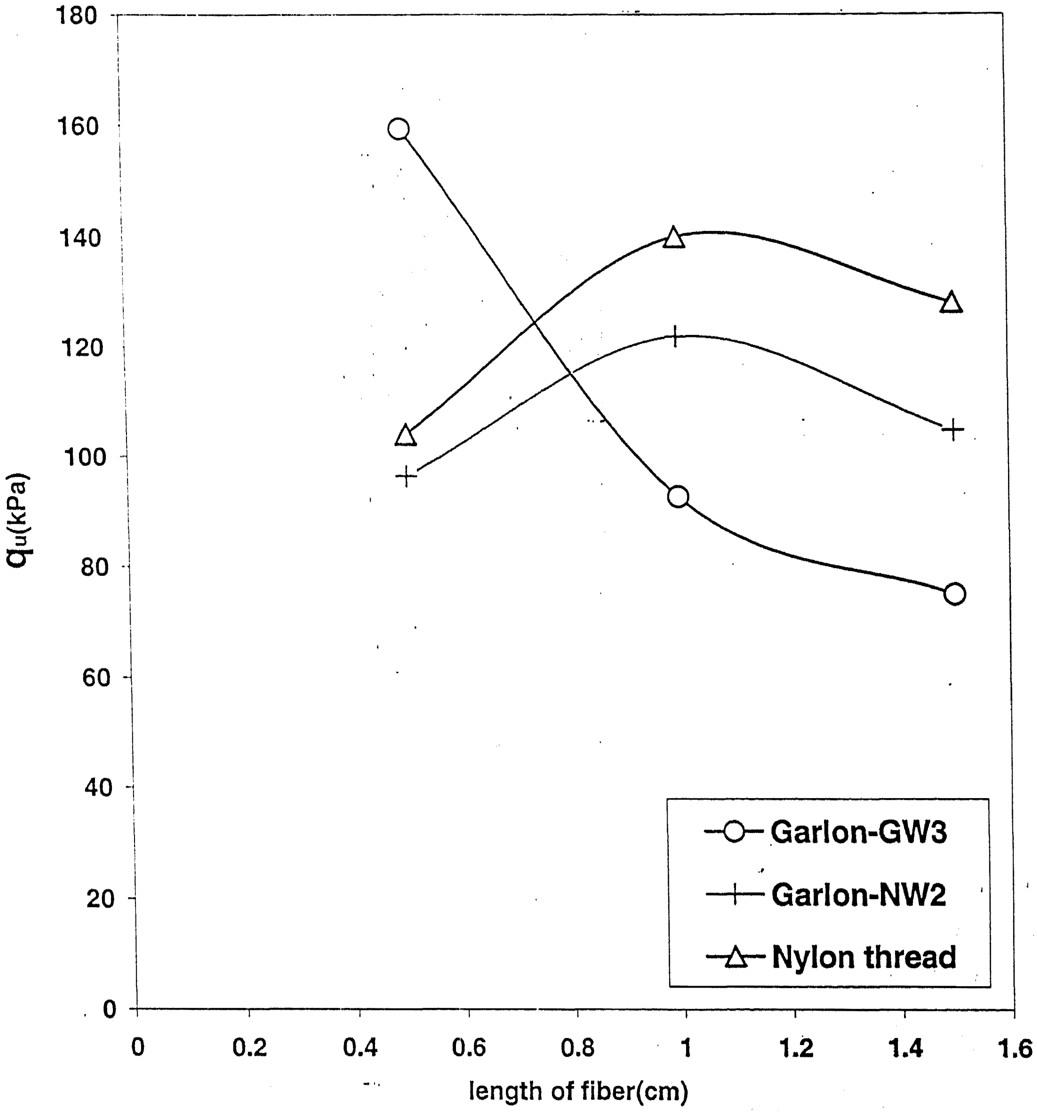


Fig. 3.12 Determination of optimum fiber length

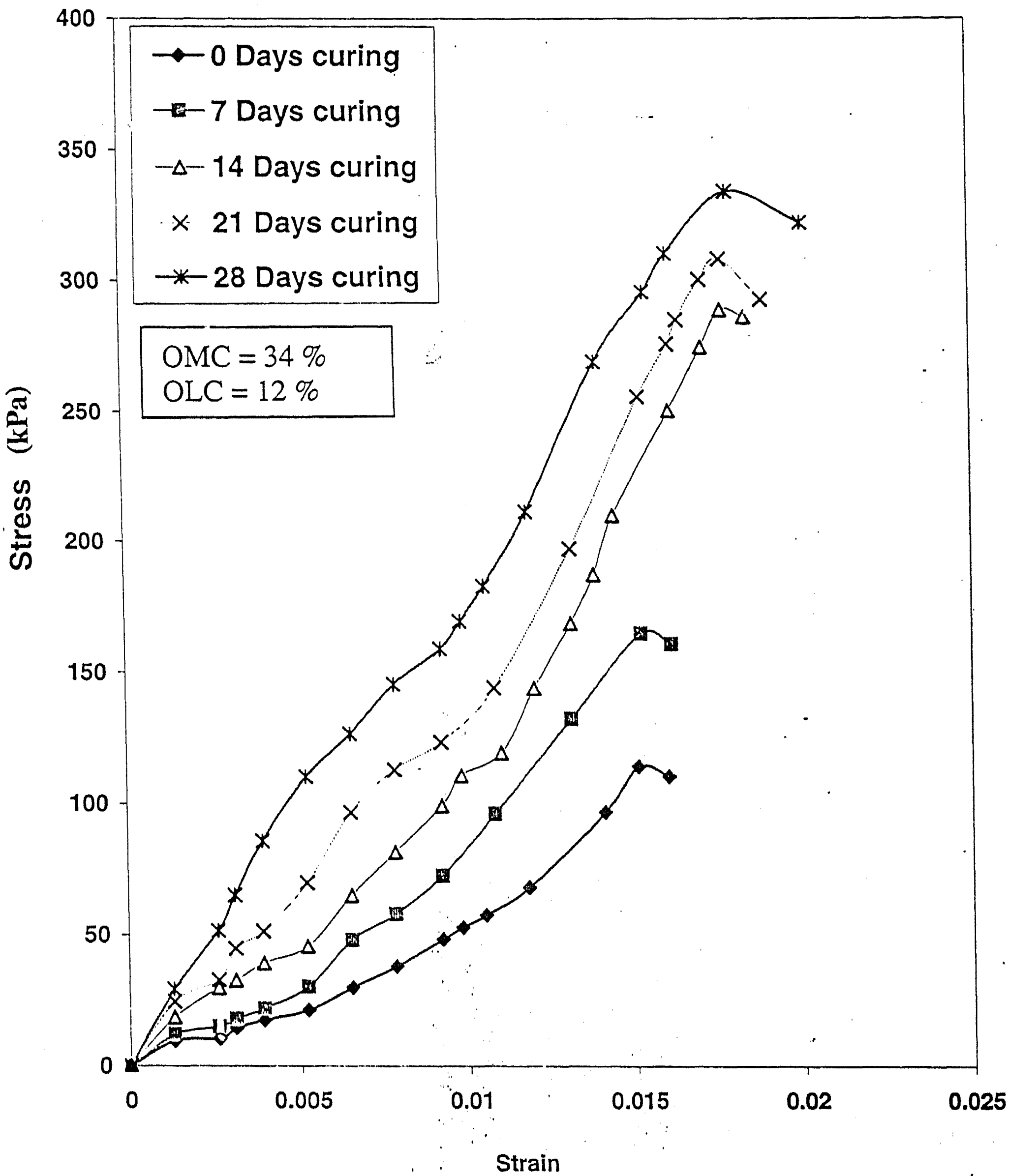


Fig. 3.13 Variation of stress- strain behavior with curing period

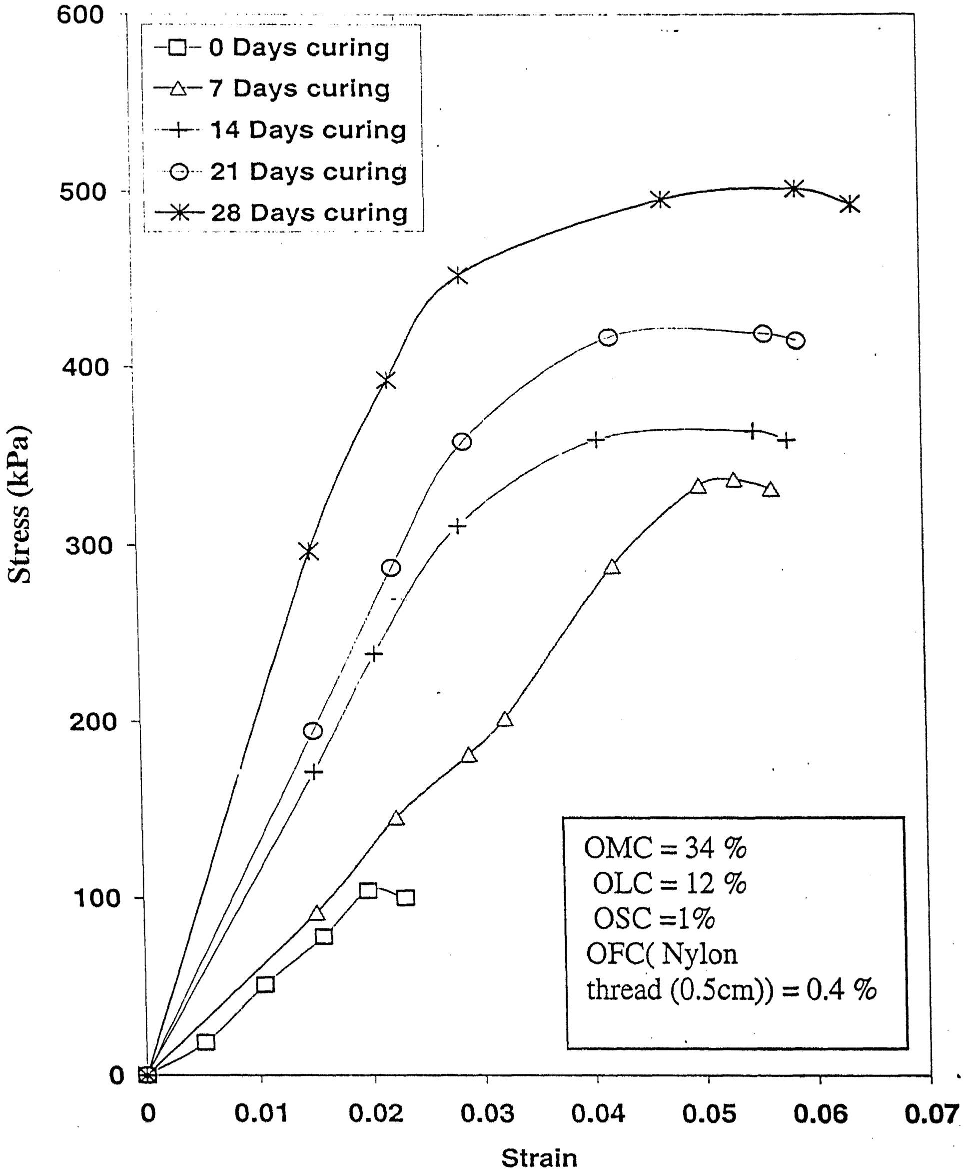


Fig. 3.15. Variation of stress- strain behavior with curing period

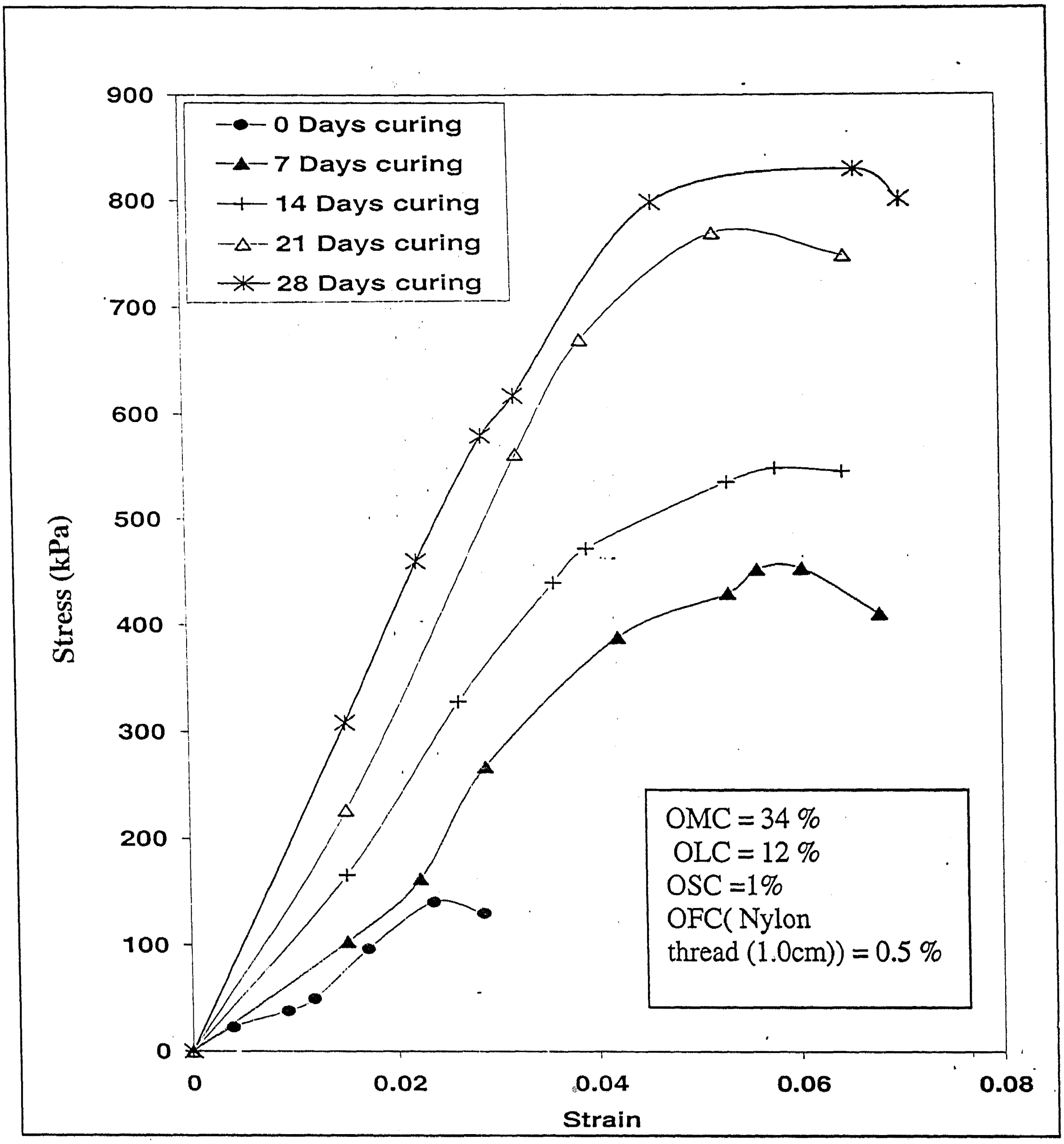


Fig. 3.16 Variation of stress- strain behavior with curing period

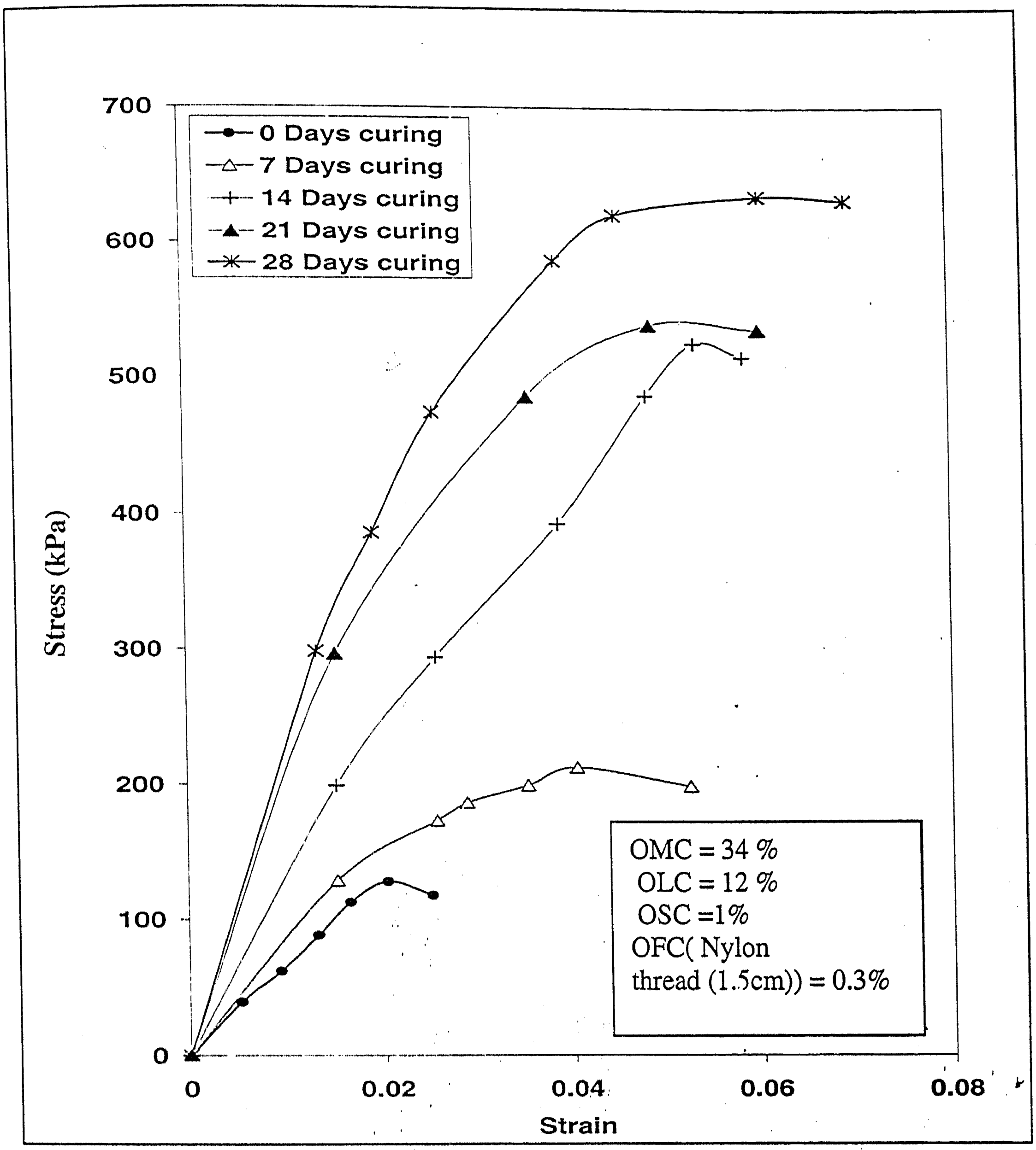


Fig. 3.17 Variation of stress- strain behavior with curing period

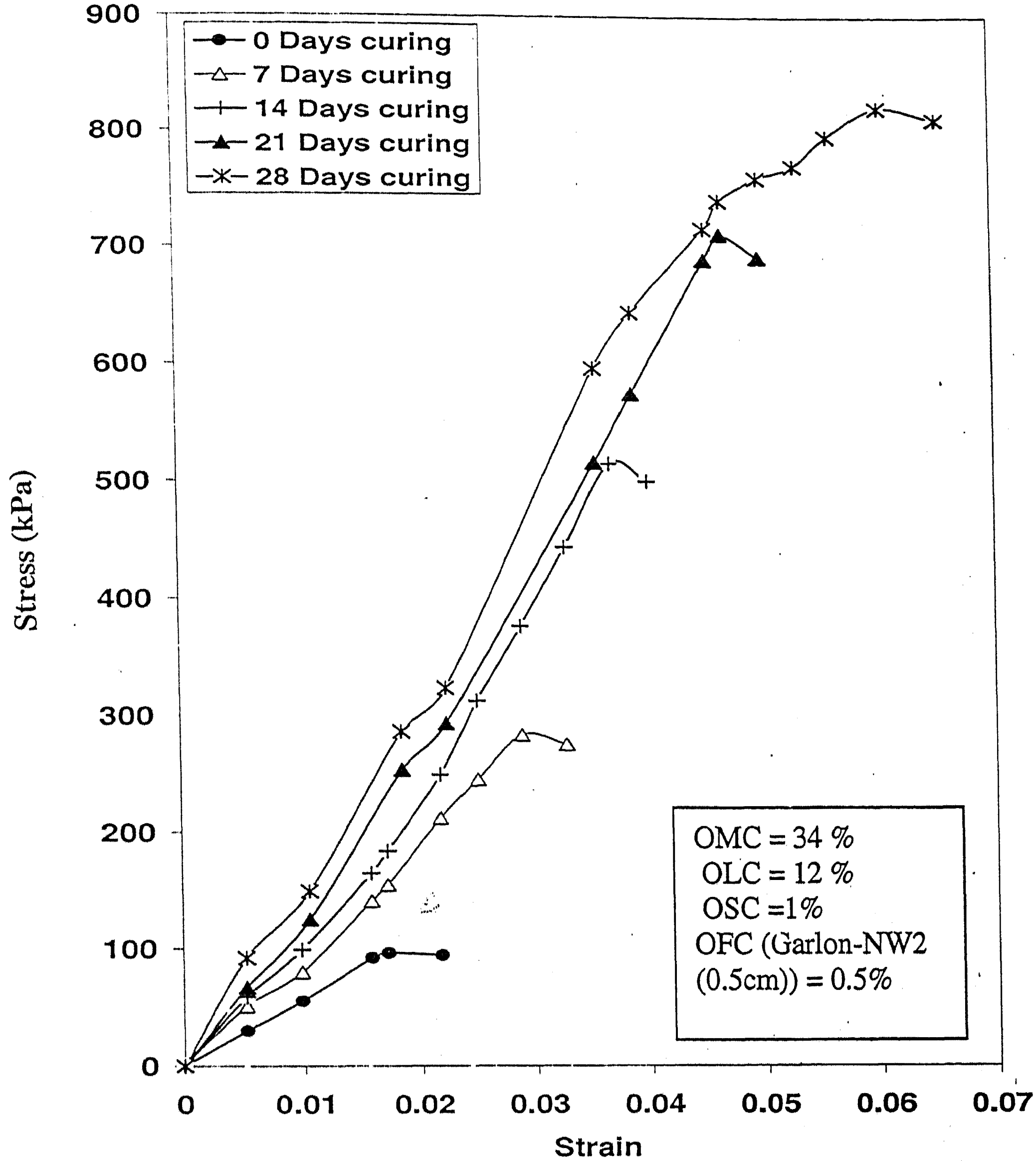


Fig. 3.18 Variation of stress- strain behavior with curing period

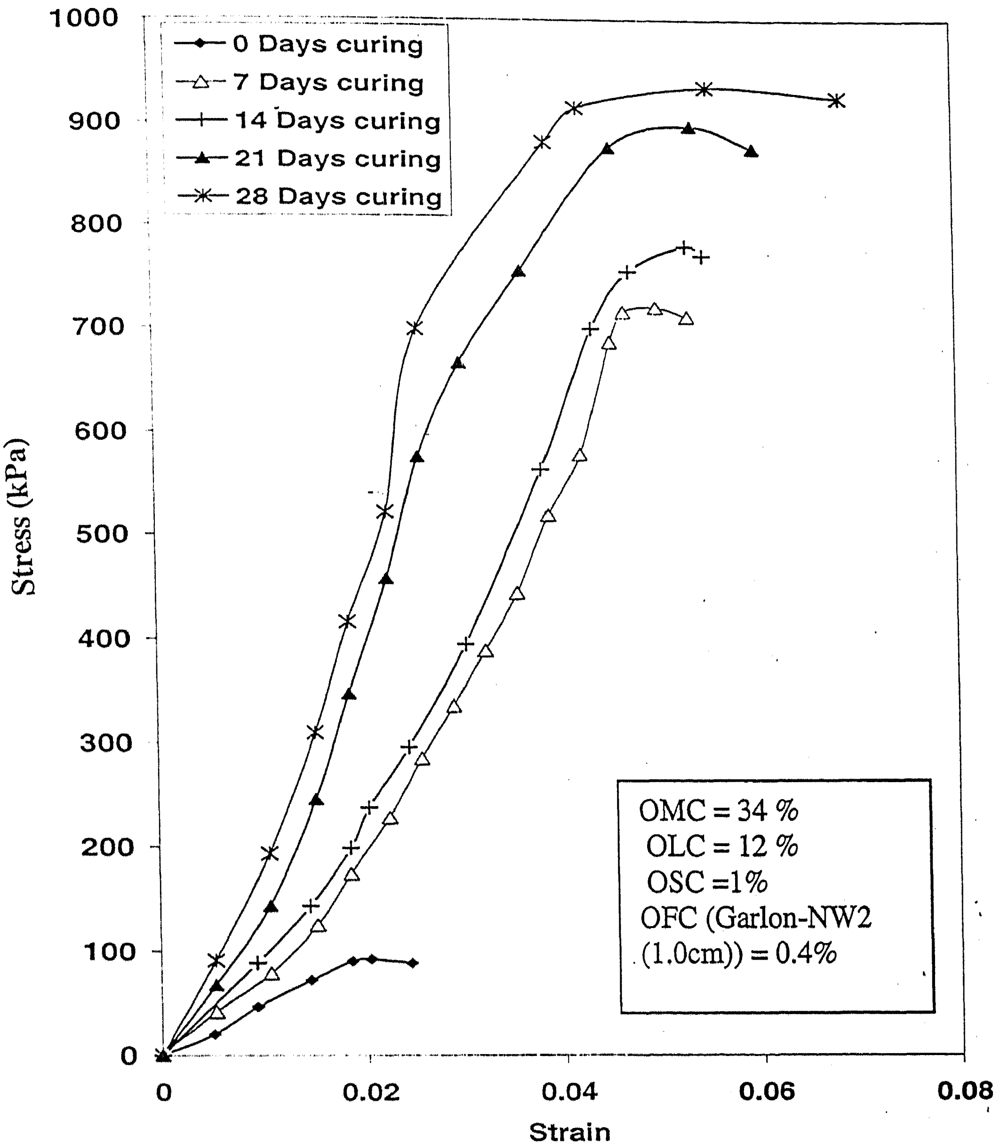


Fig. 3.19 Variation of stress- strain behavior with curing period

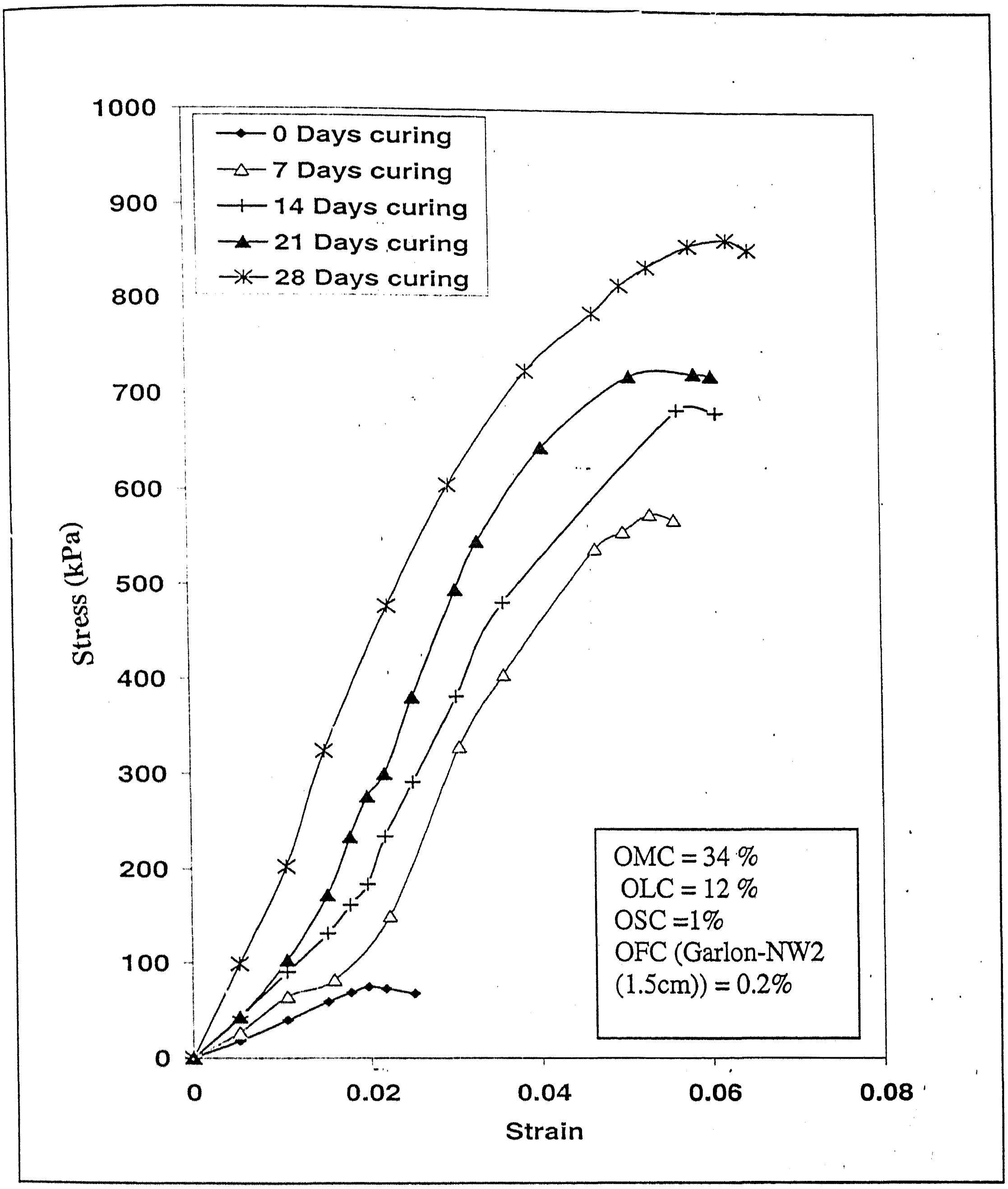


Fig. 3.20 Variation of stress- strain behavior with curing period

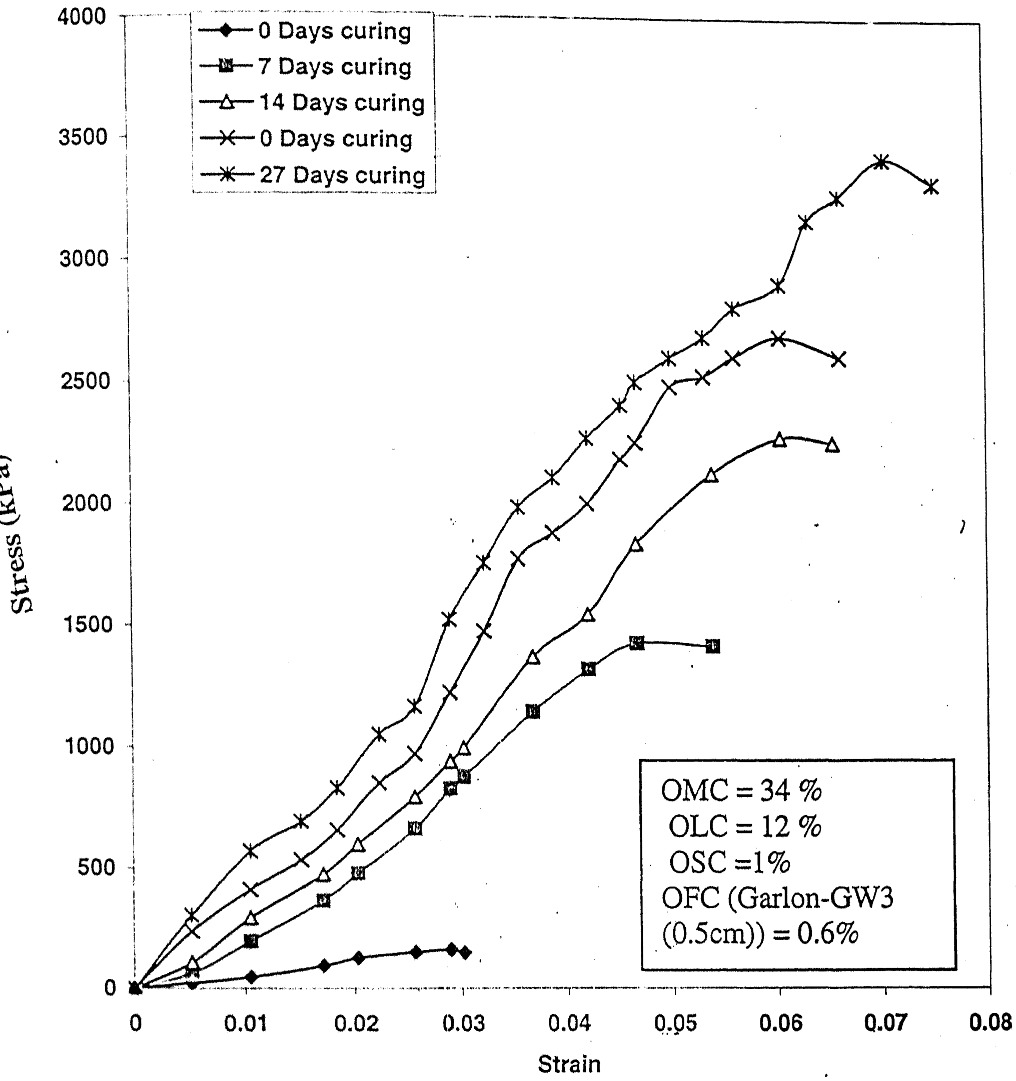


Fig. 3.21 Variation of stress- strain behavior with curing period

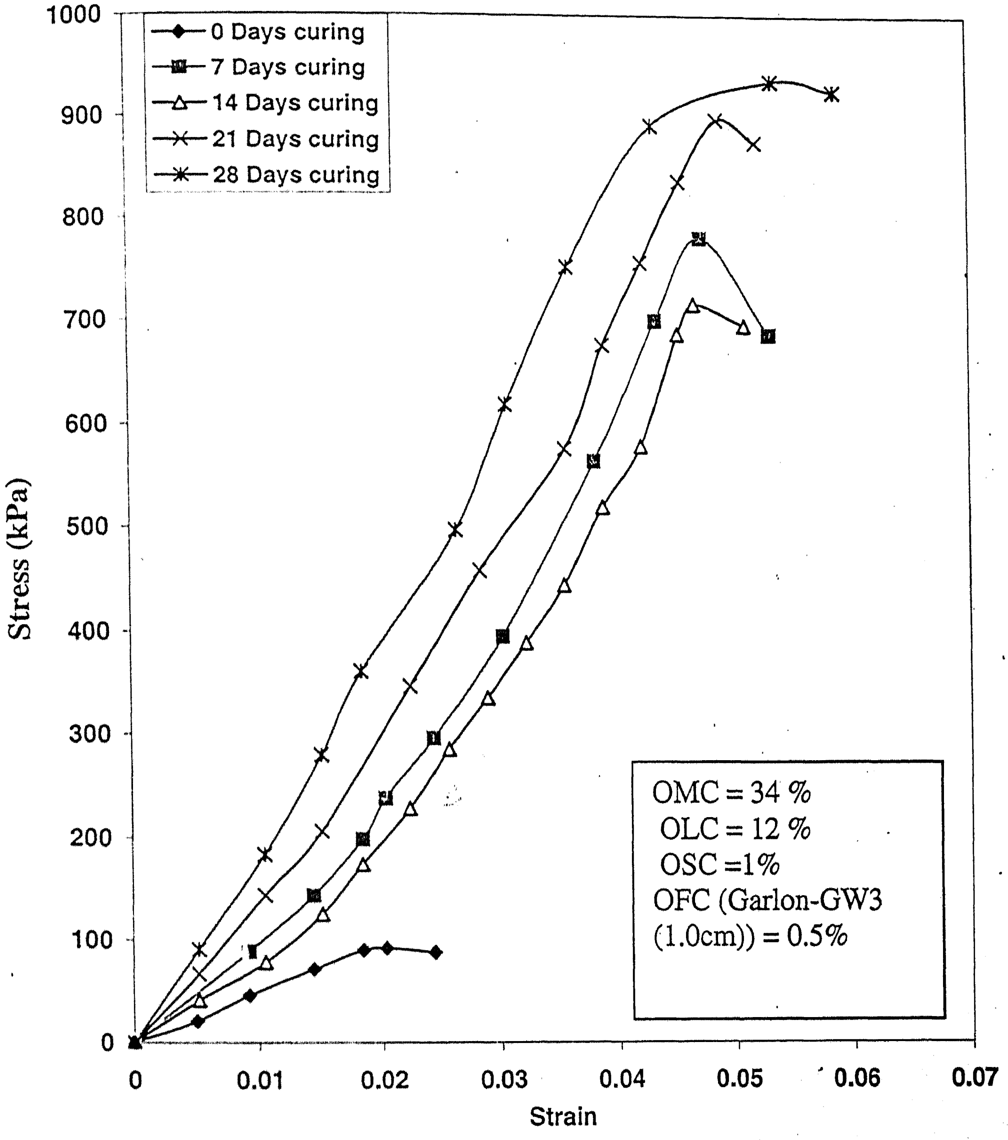


Fig. 3.22 Variation of stress- strain behavior with curing period

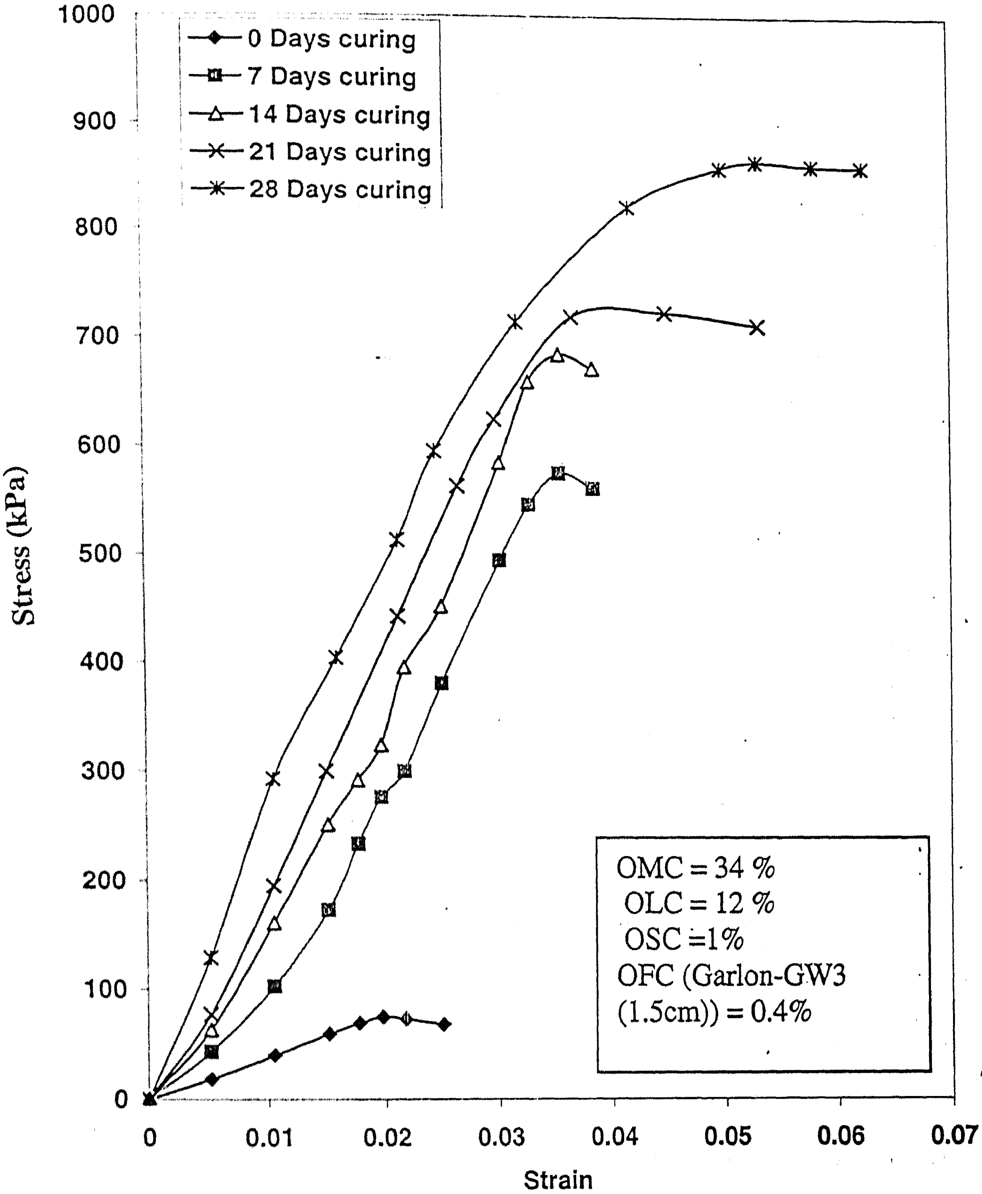


Fig. 3.23 Variation of stress- strain behavior with curing period

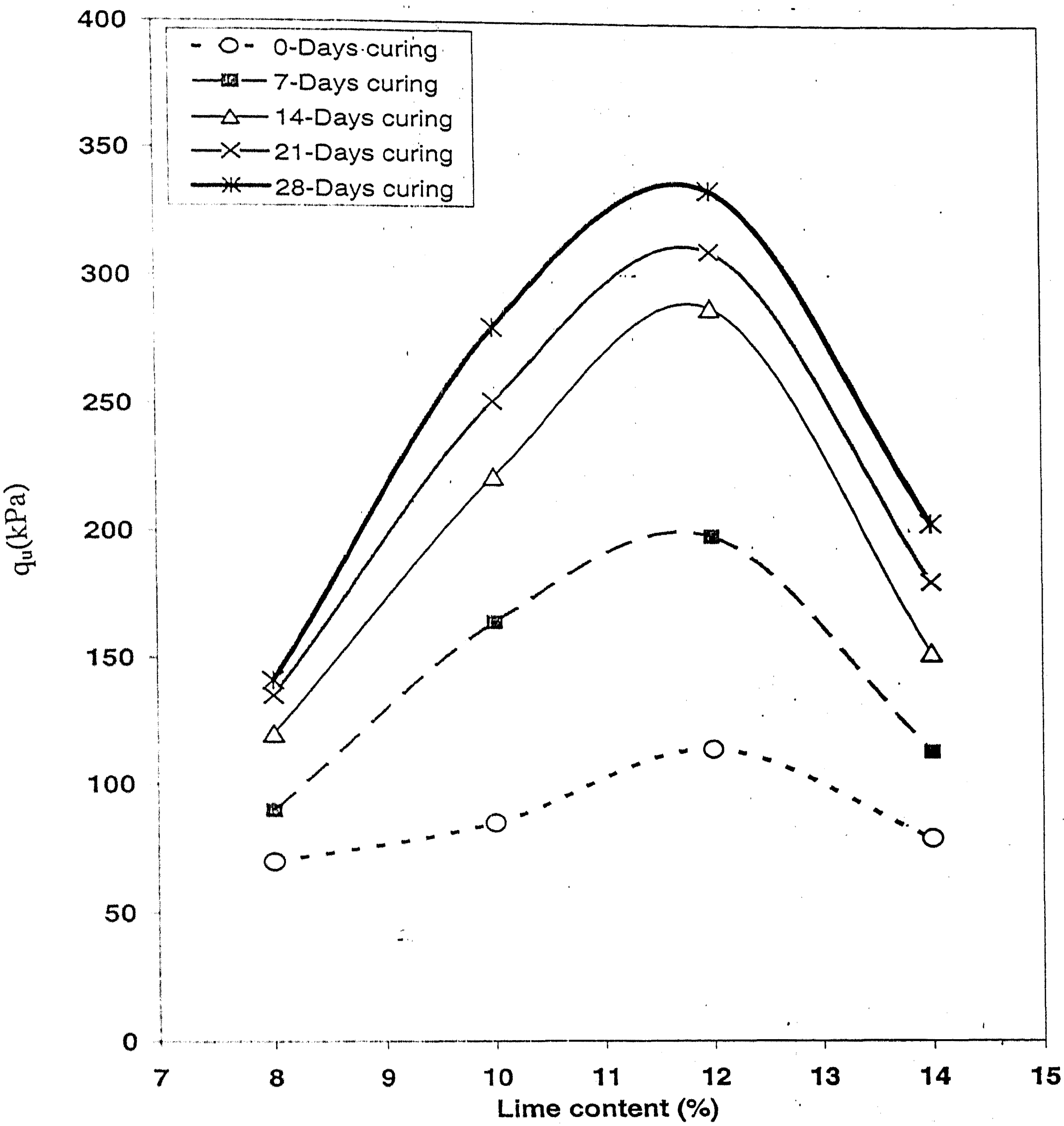


Fig. 3.24 Variation of unconfined compressive strength with lime content with different curing period

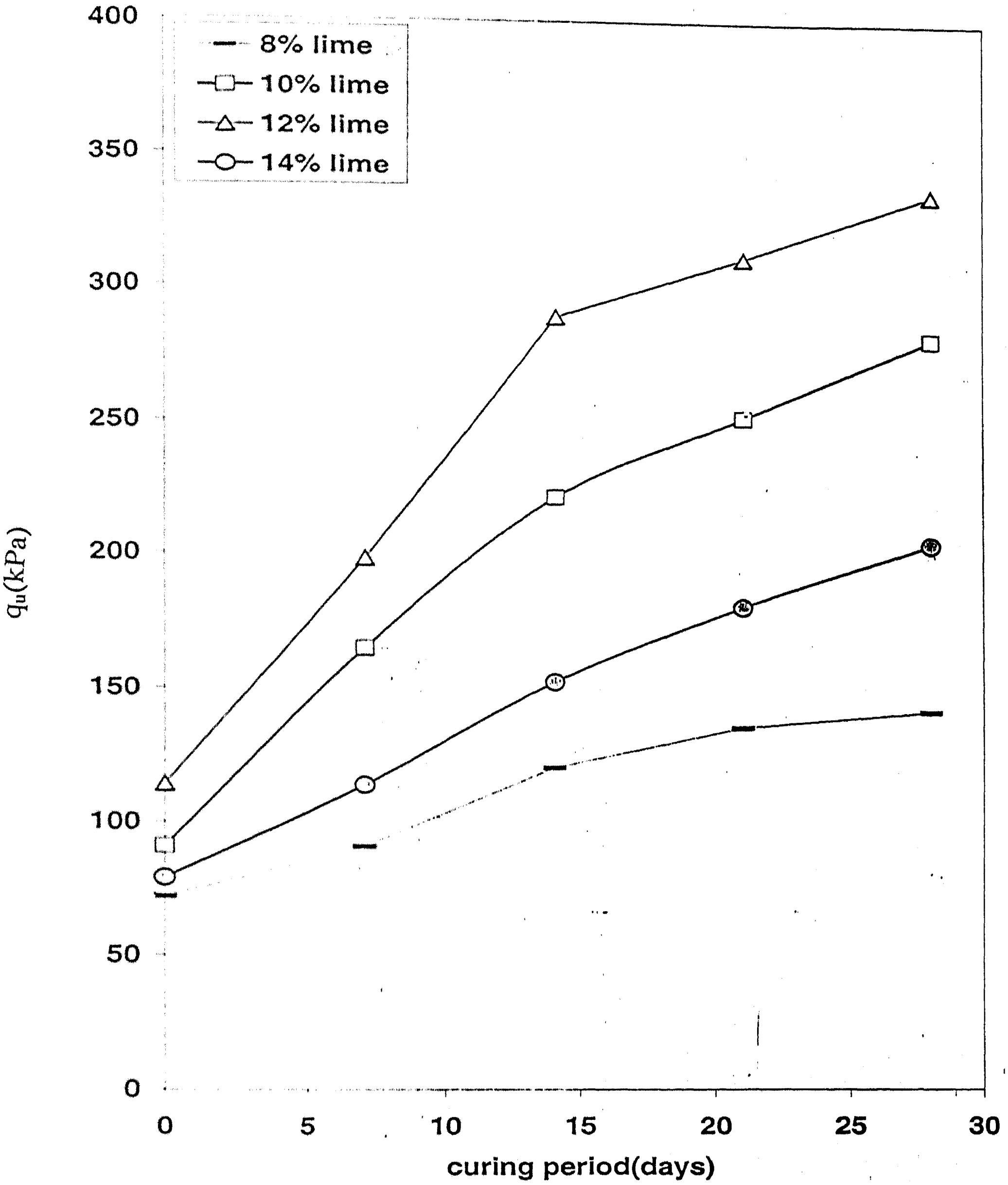


Fig. 3.25 Variation of unconfined compressive strength with curing period with different lime content

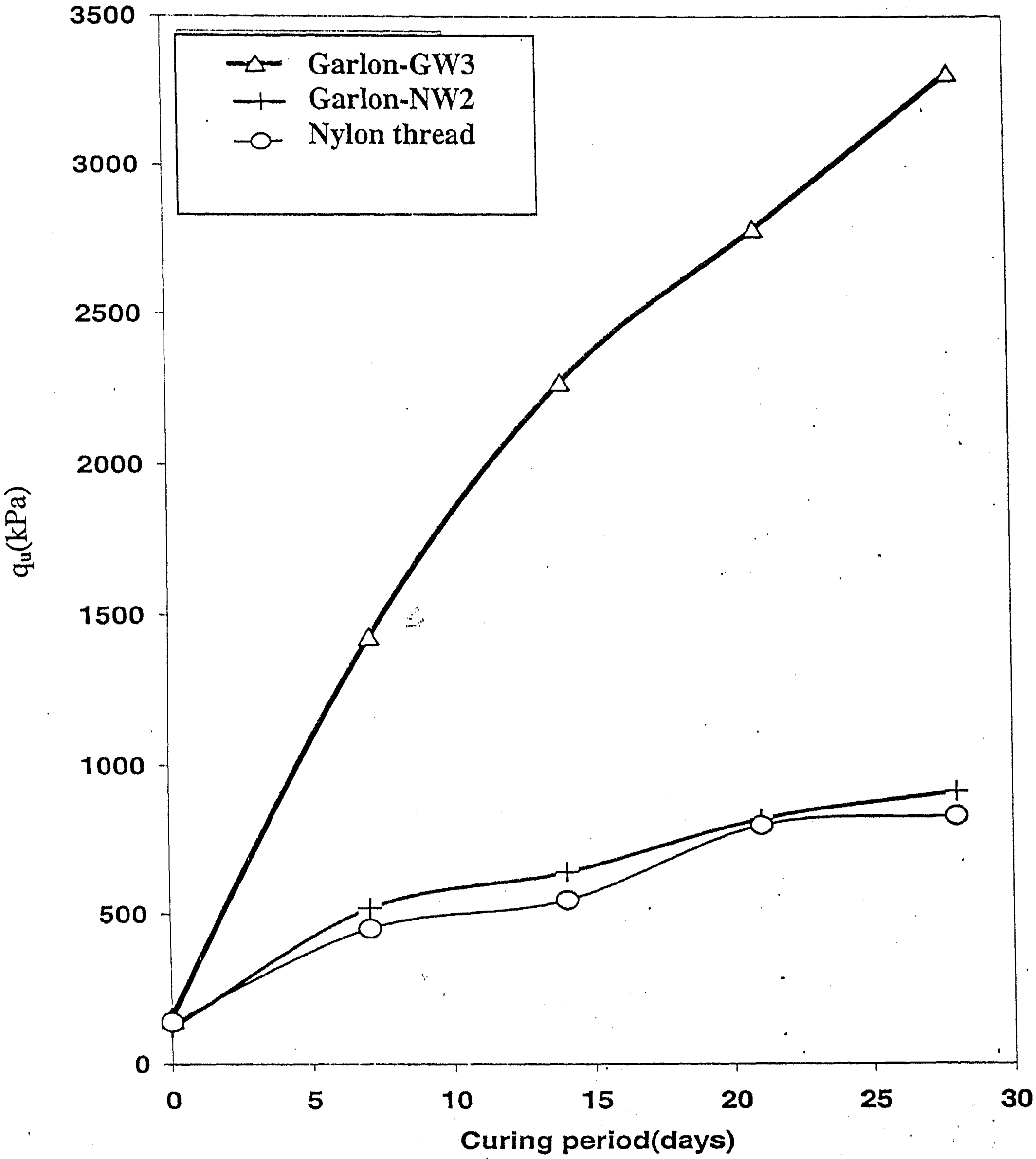


Fig. 3.26 Variation of unconfined compressive strength with curing period with different fibers

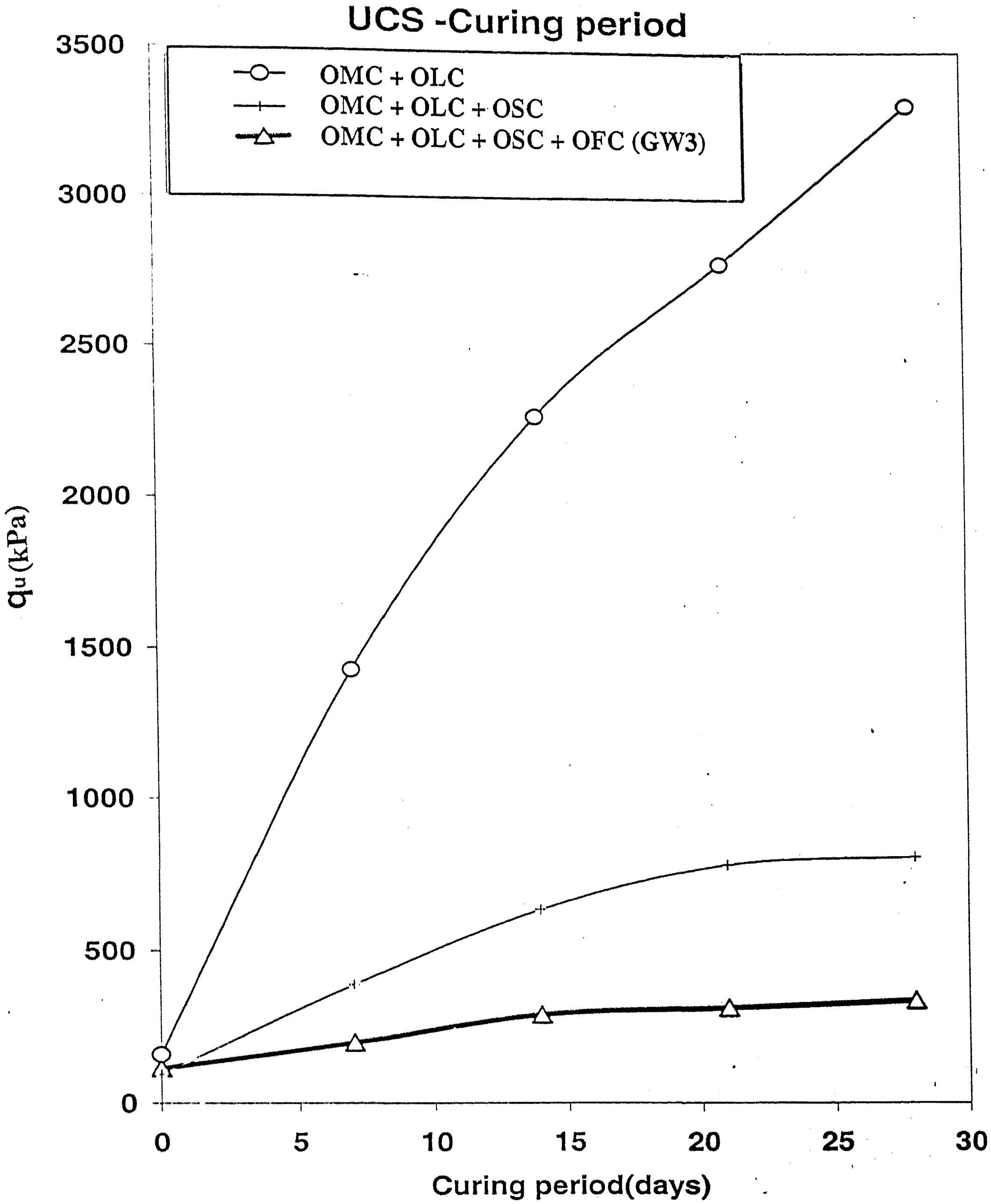


Fig. 3.27 Comparison of the variation of q_u with curing period for samples with different admixtures

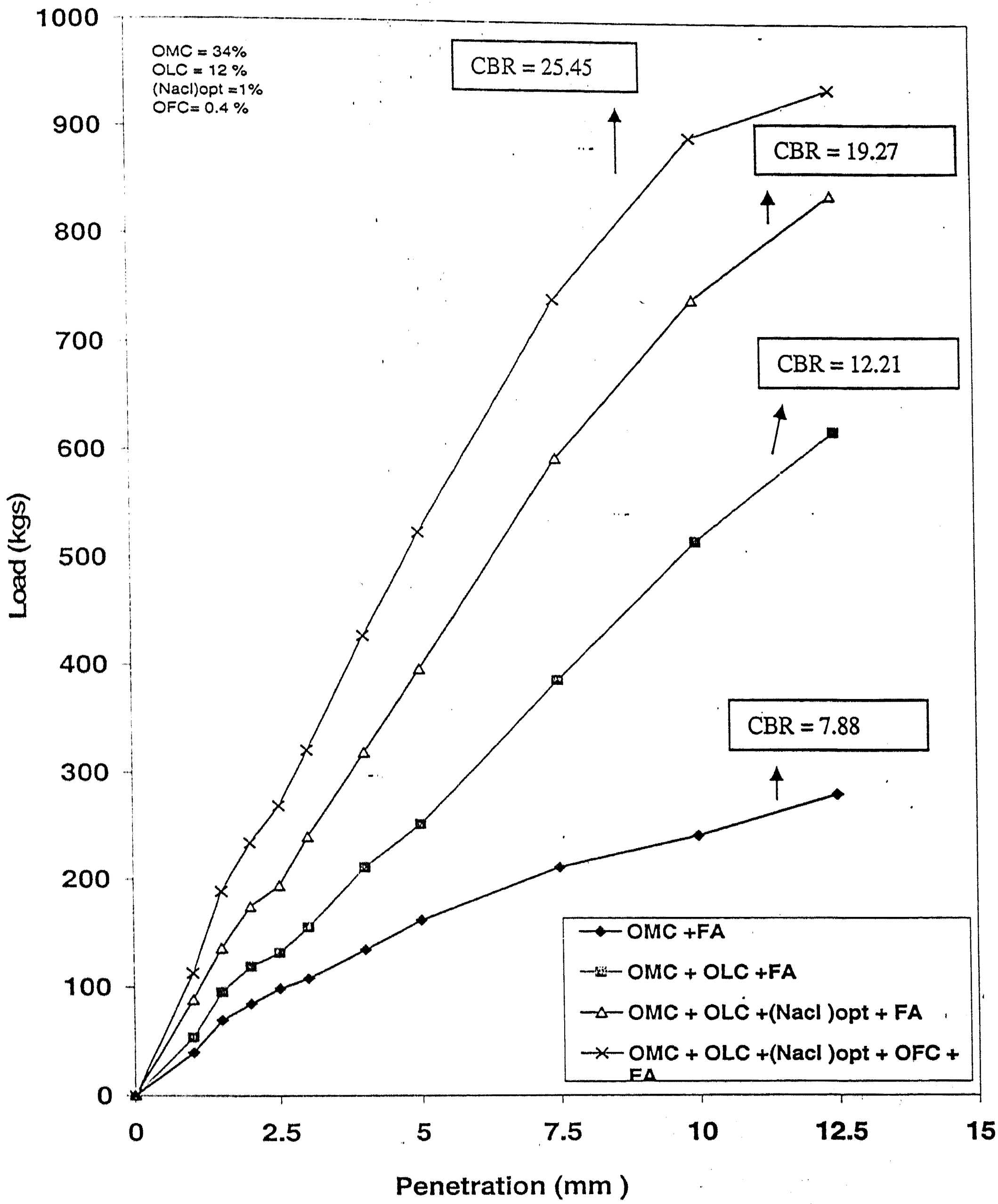


Fig. 3.28 CBR test result (unsoaked condition)
Load versus penetration curve

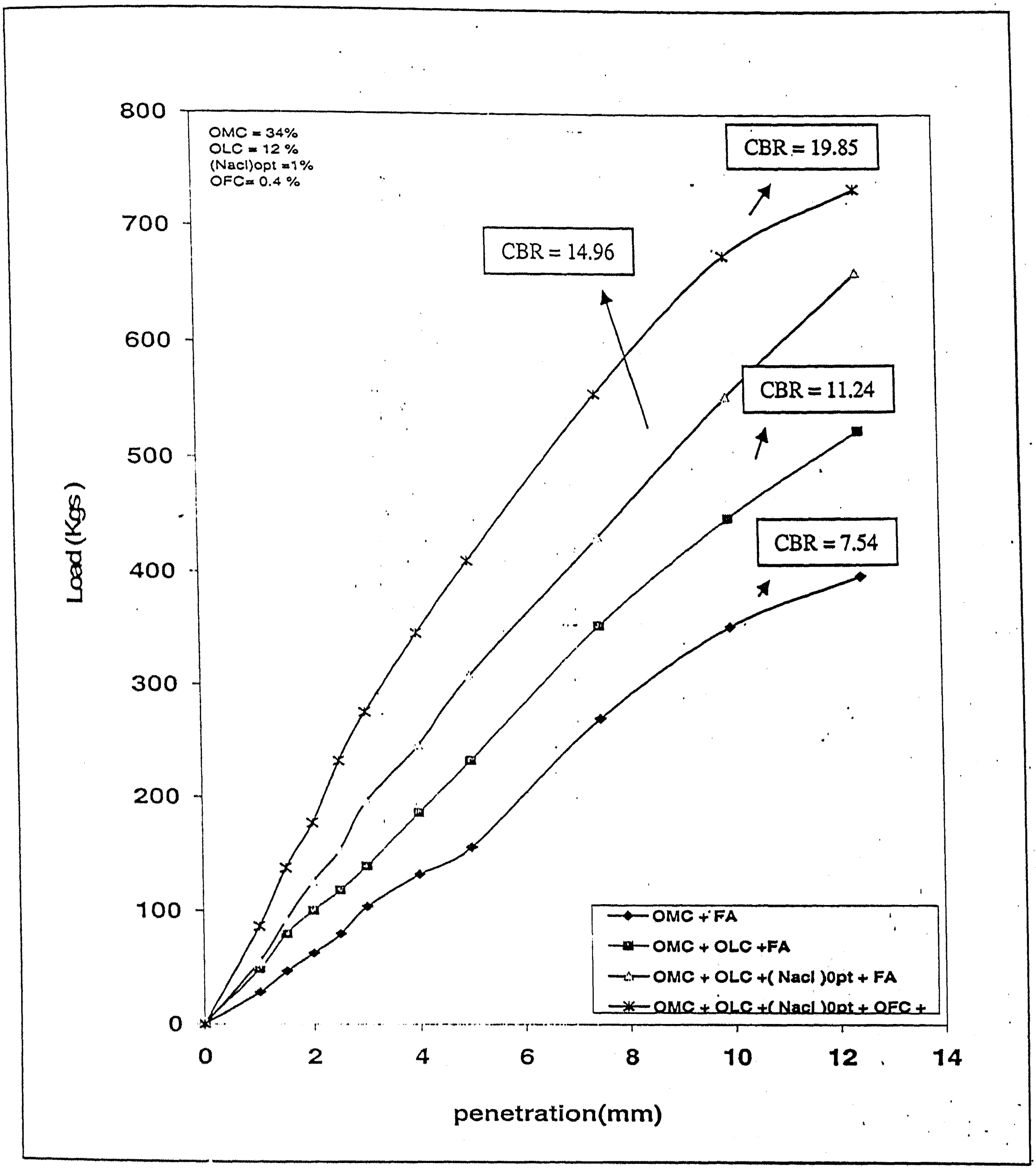


Fig. 3.29 CBR test result (soaked condition)
Load versus penetration curve

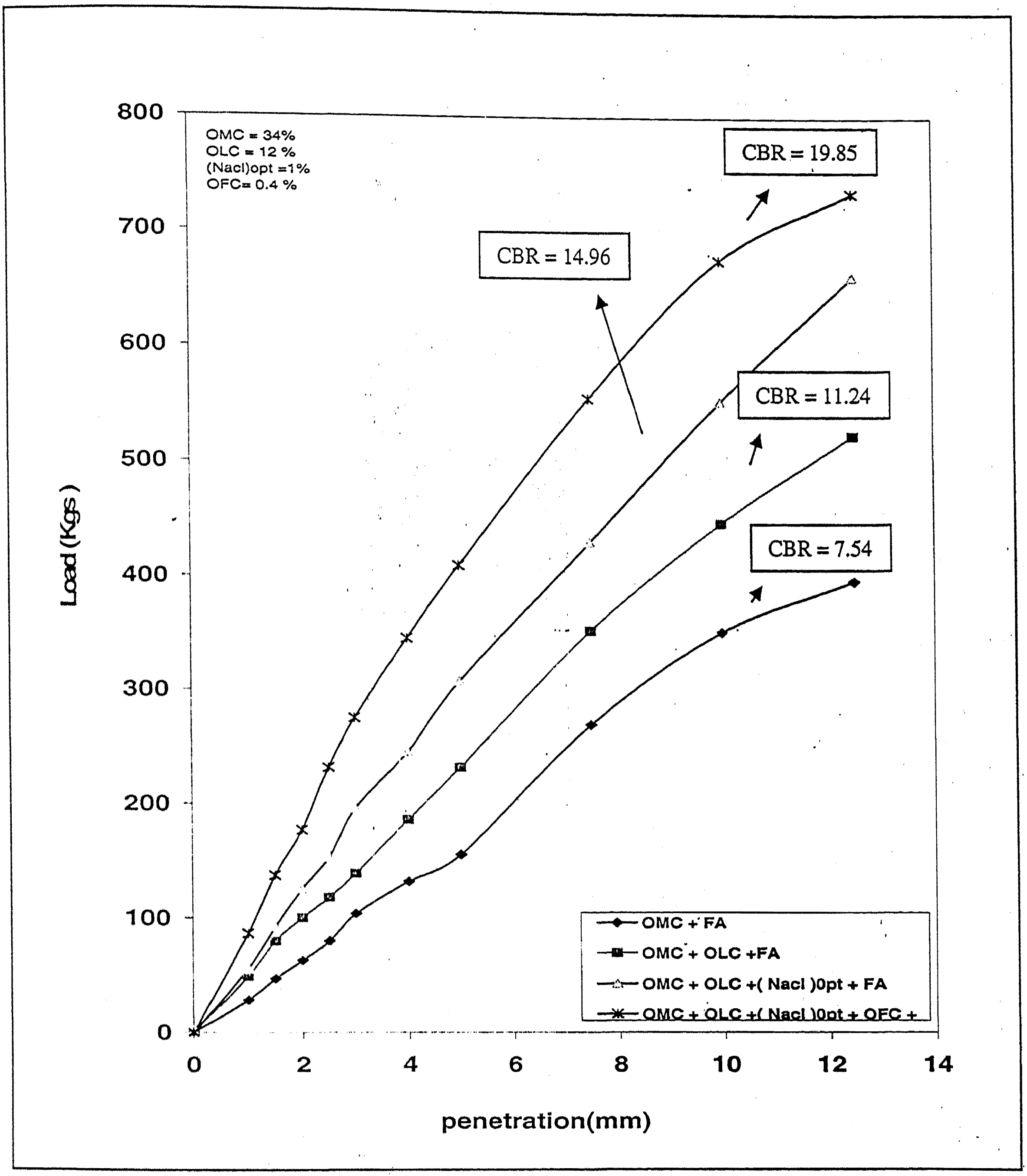


Fig. 3.29 CBR test result (soaked condition)
Load versus penetration curve

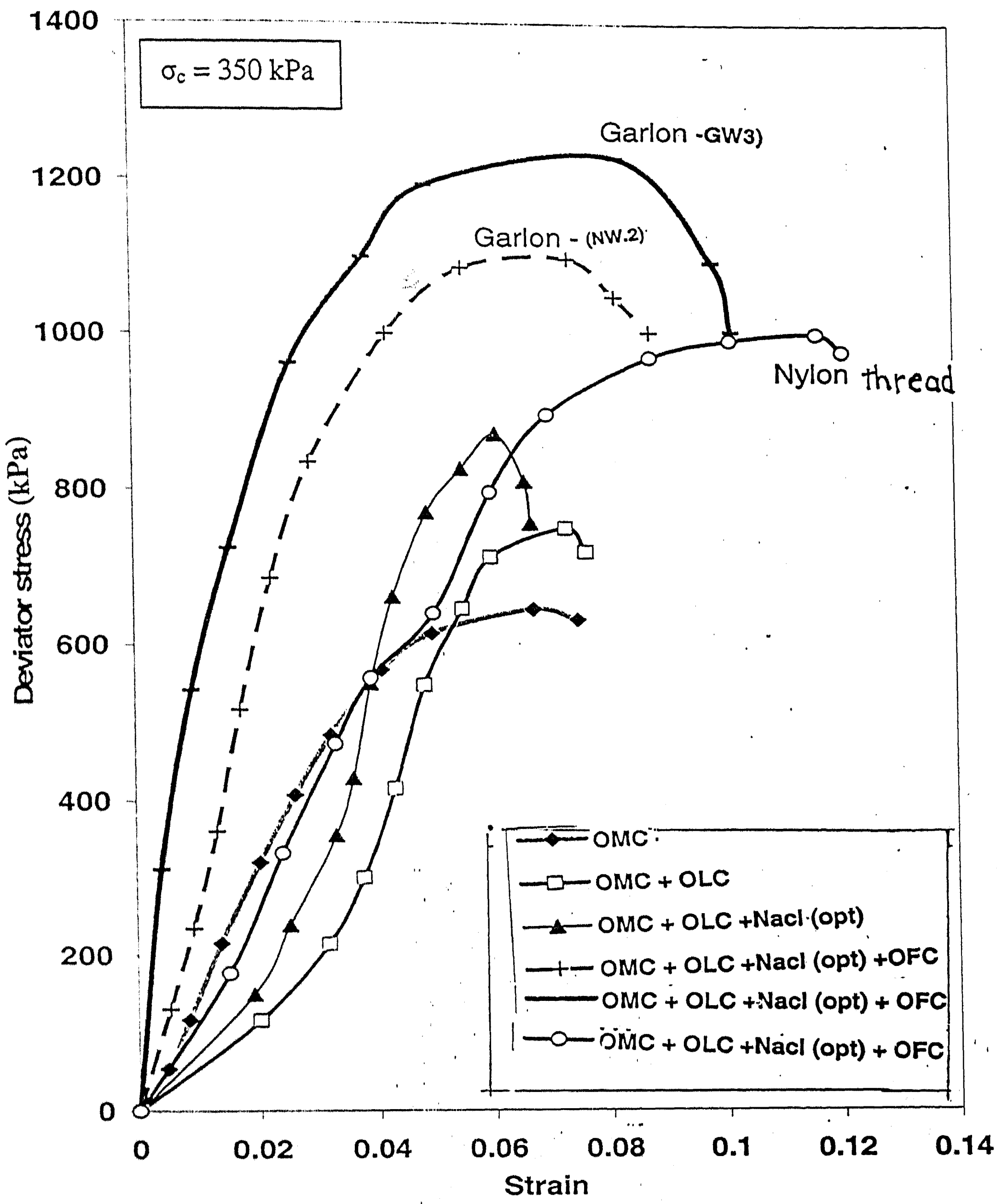


Fig. 3.30 Stress-strain diagram(CU test)

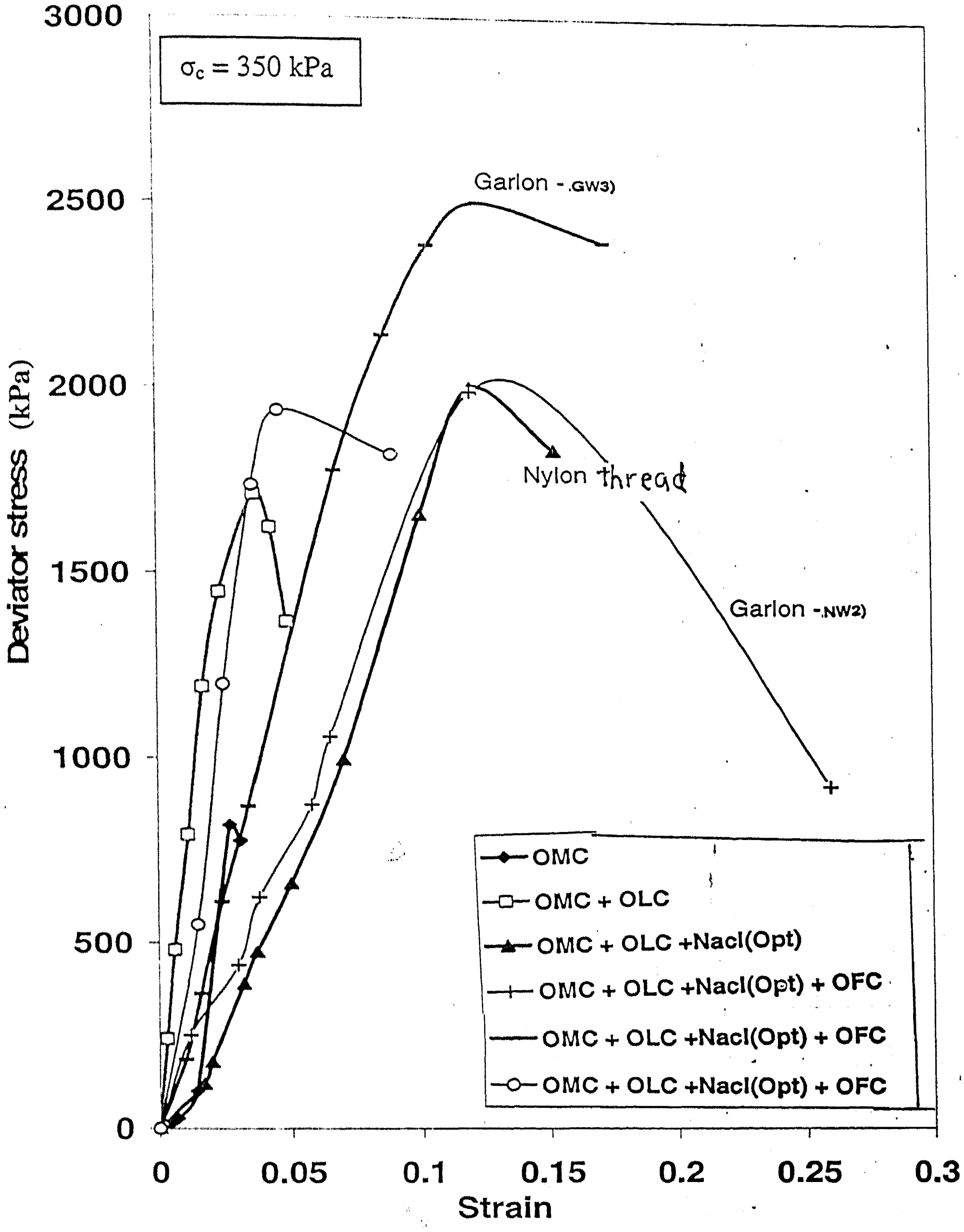


Fig. 3.31 Stress-strain diagram(CD test)

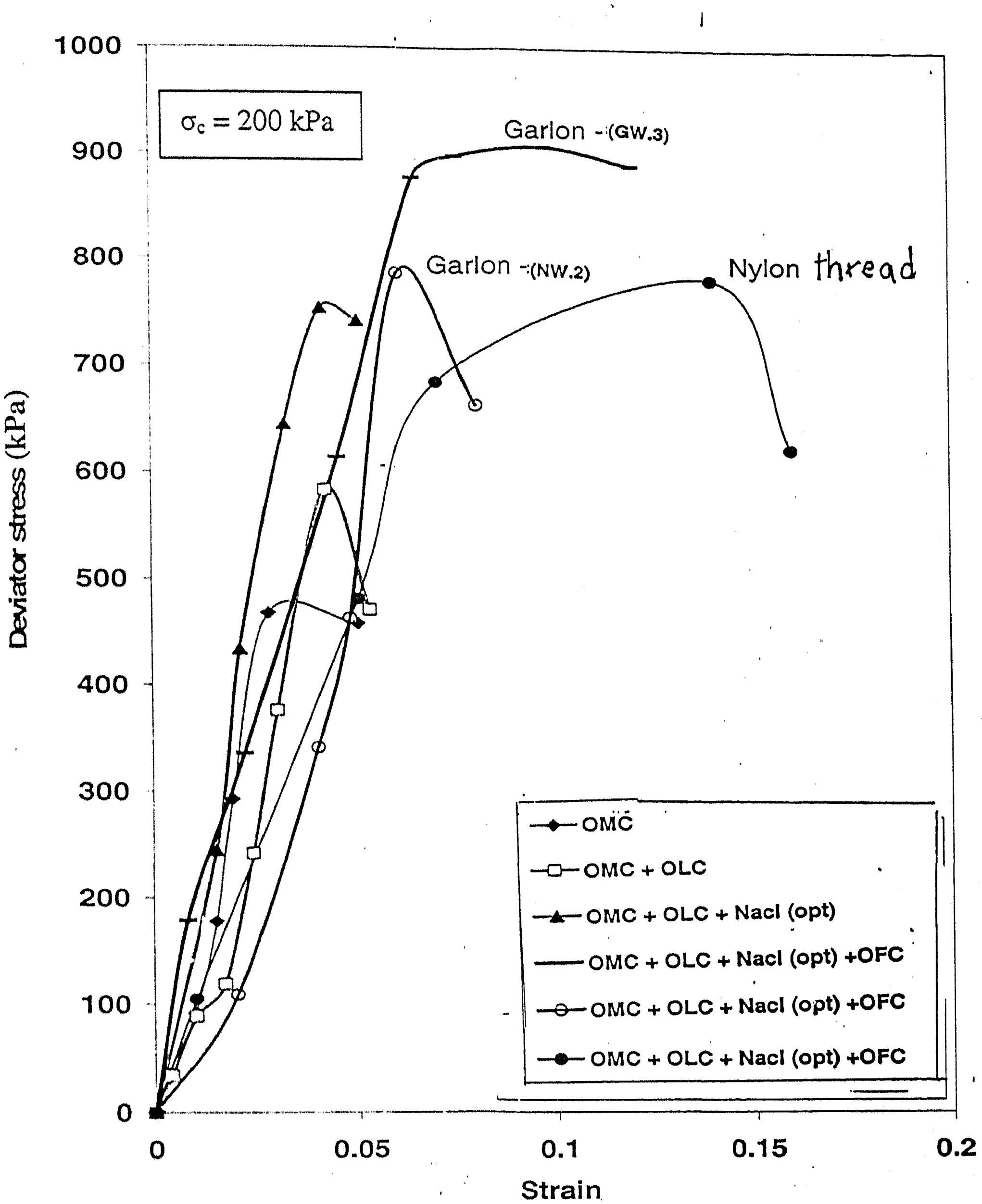


Fig. 3.32 Stress-strain diagram(CU test)

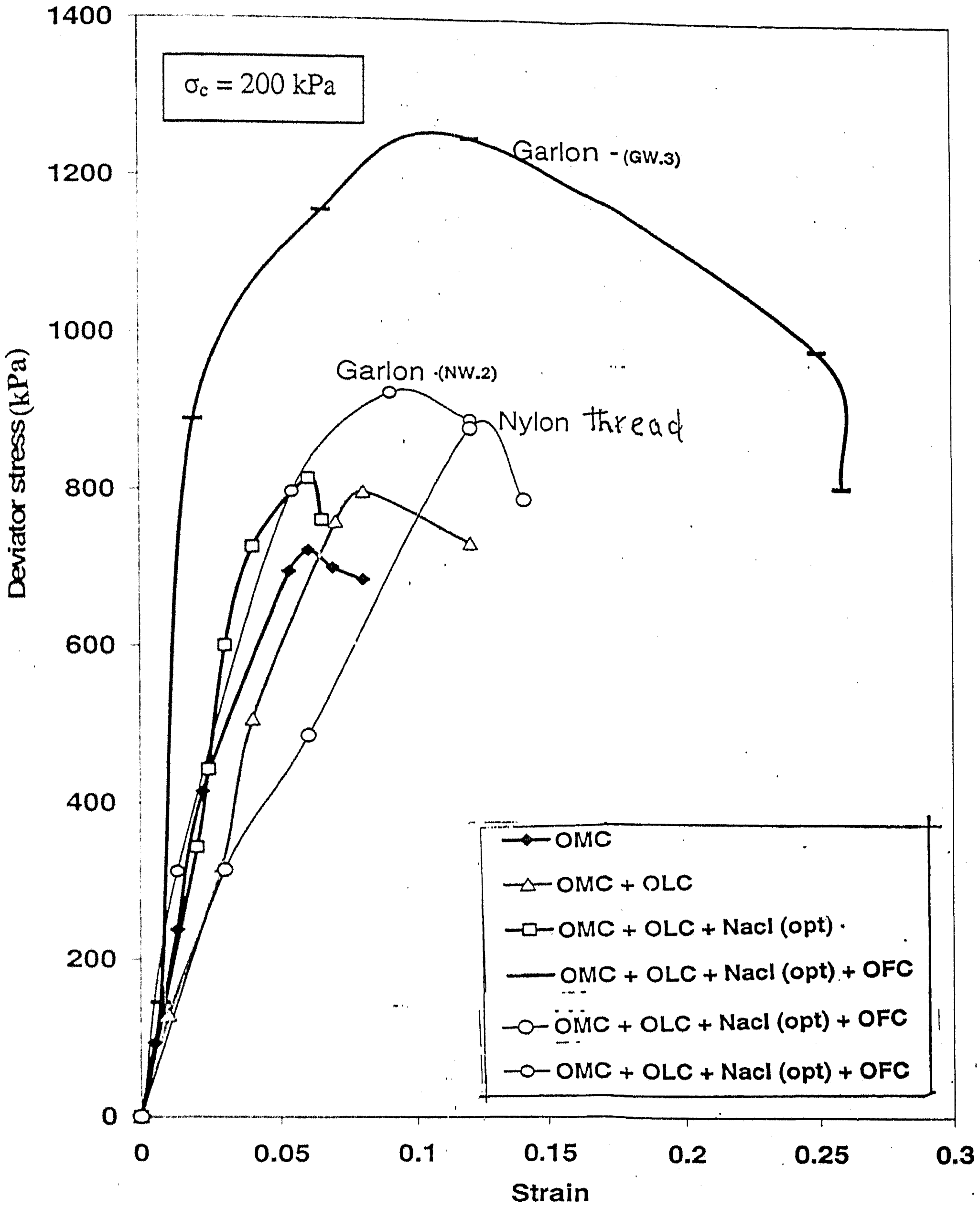


Fig. 3.33 Stress-strain diagram(CD test)

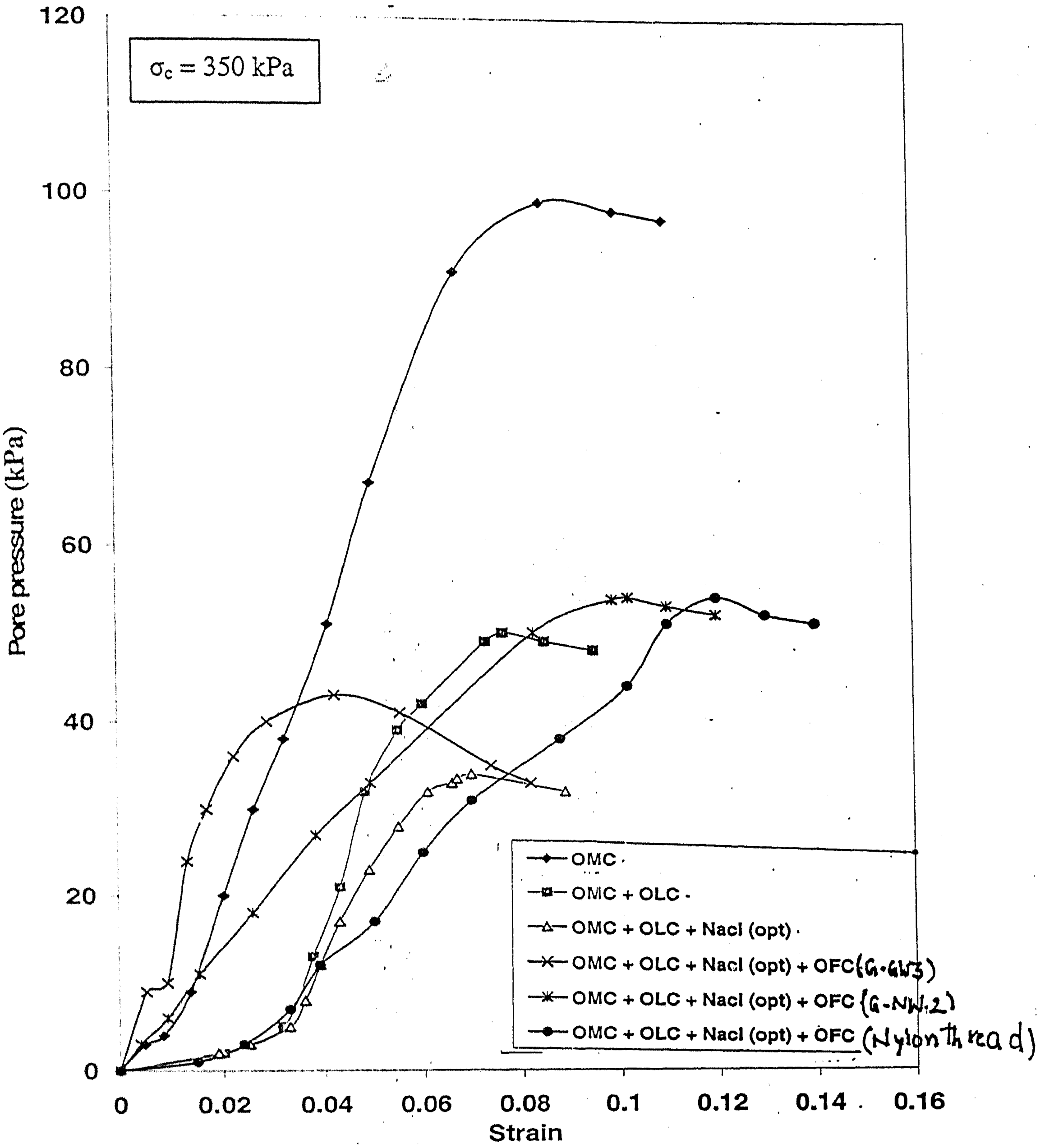


Fig. 3.34 Pore pressure – strain response (CU test)

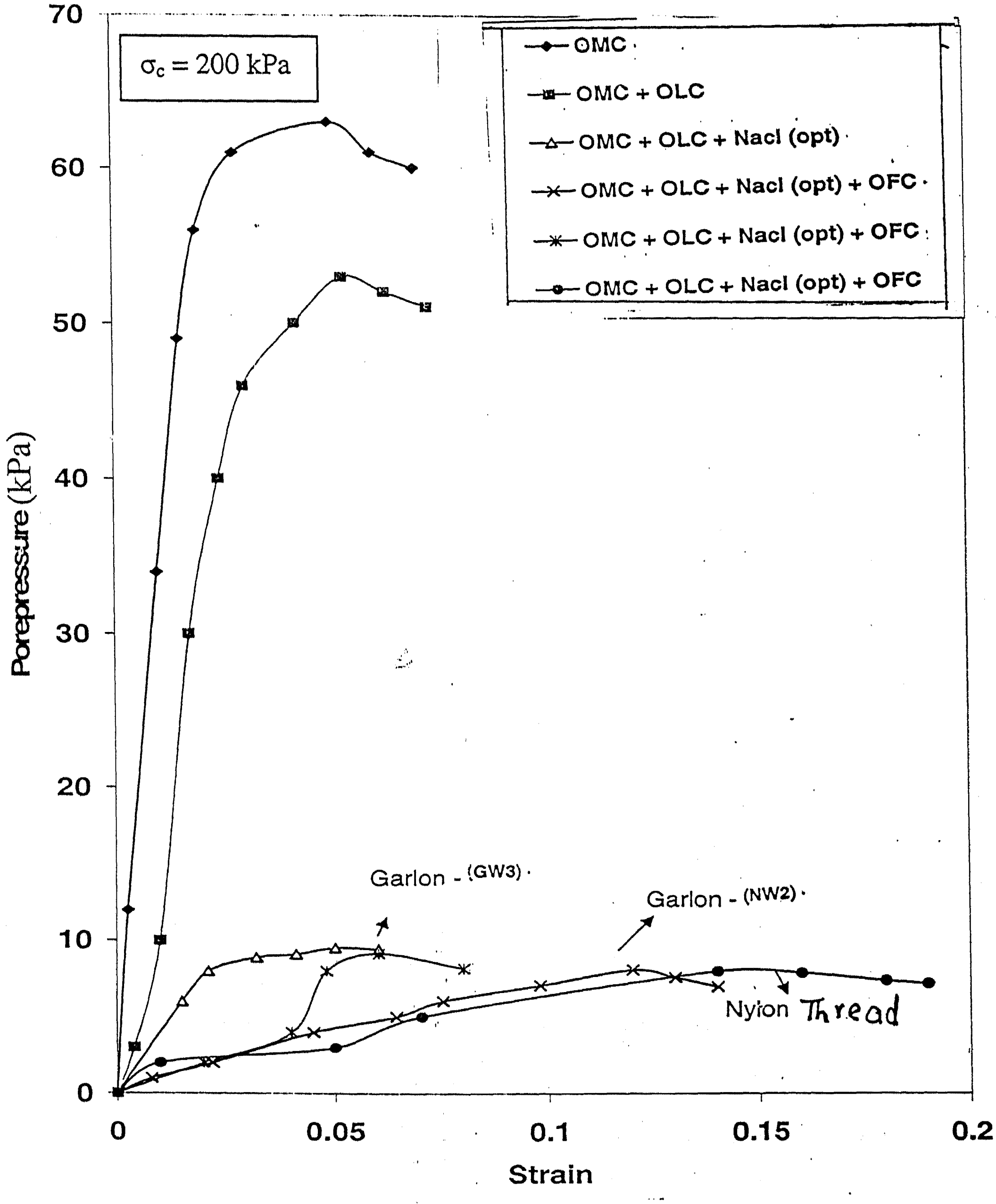


Fig. 3.35 Pore pressure – strain response (CU test)

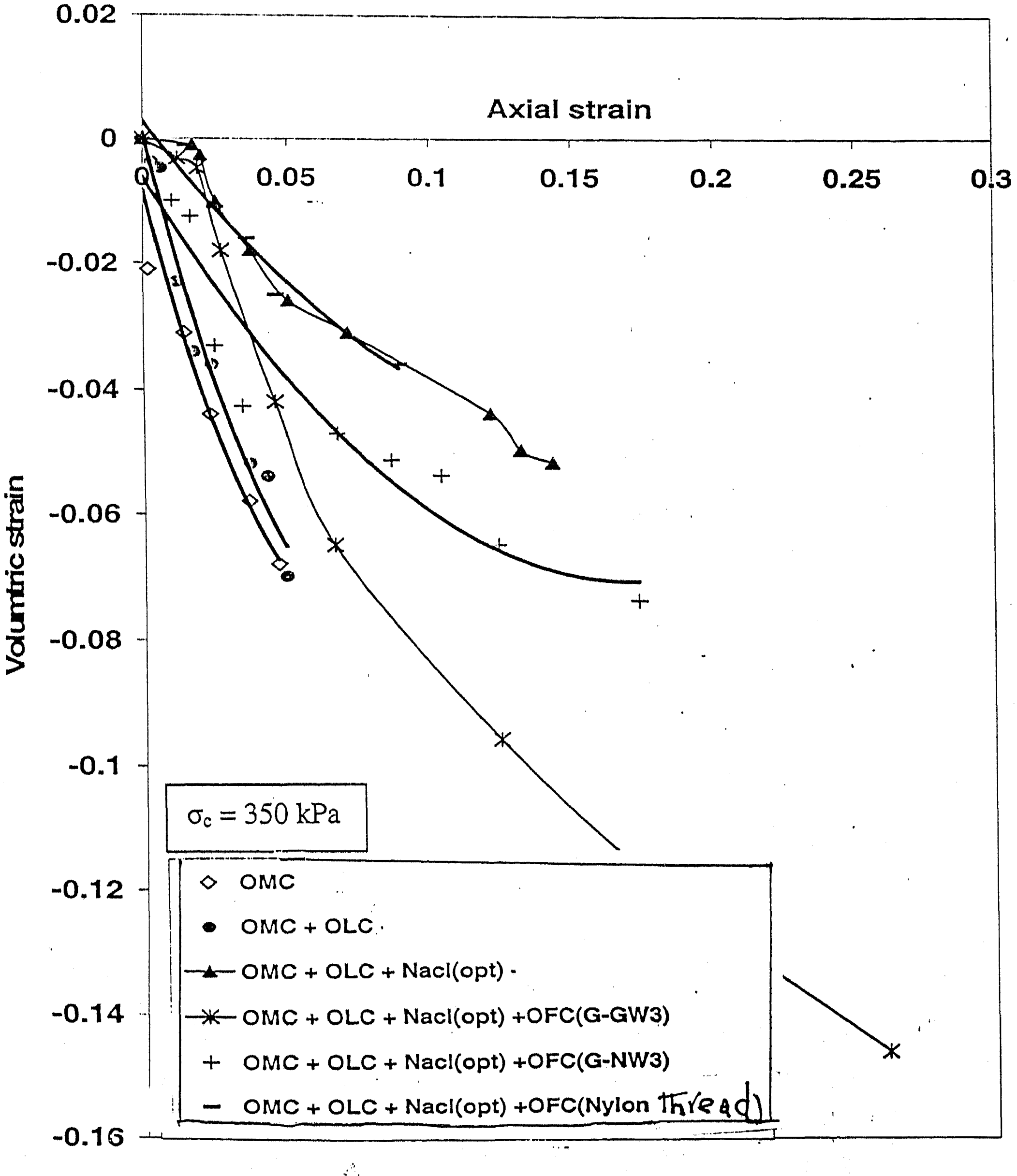


Fig. 3.36 Volumetric strain versus axial strain response (CD test)

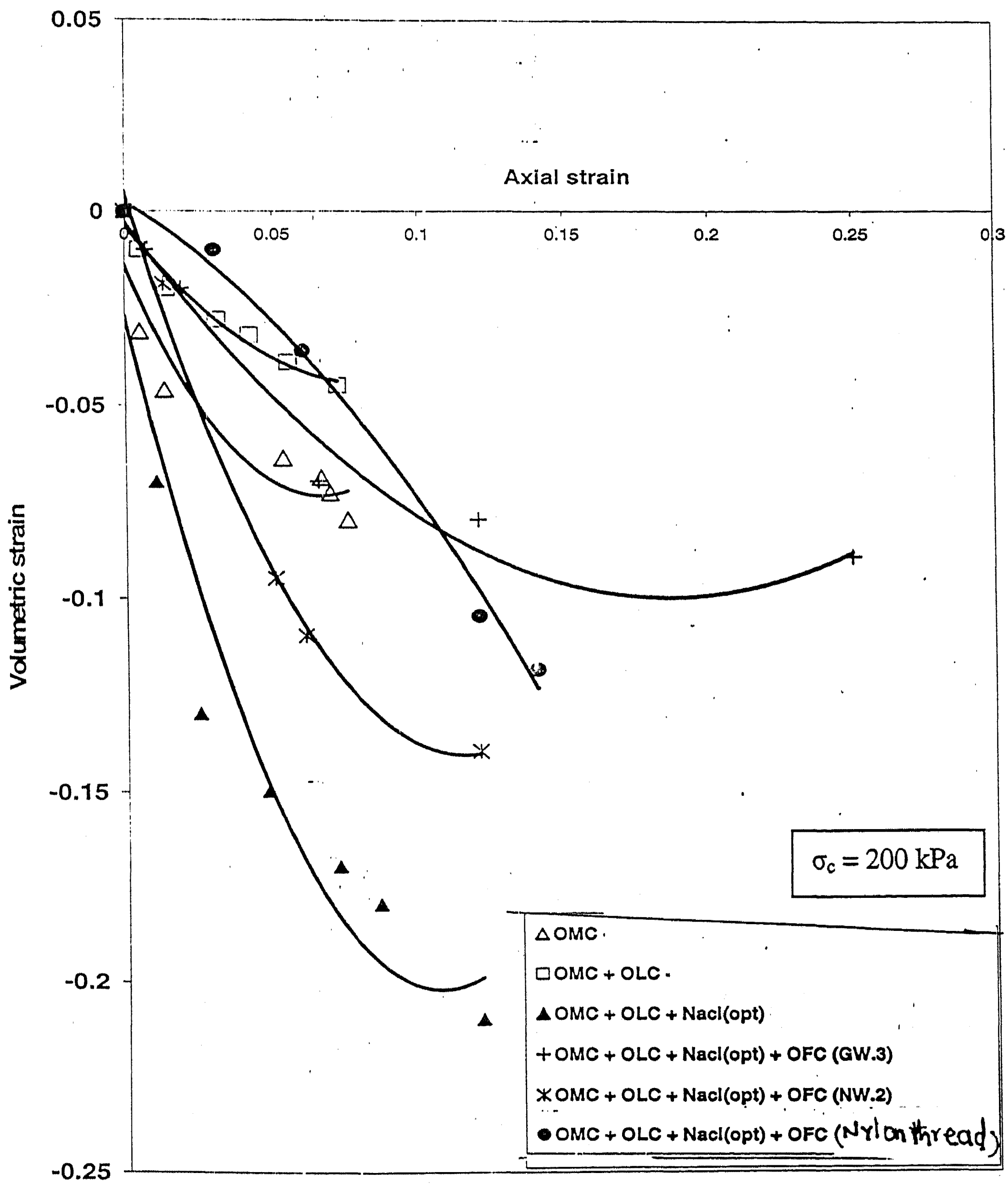


Fig. 3.37 Volumetric strain versus axial strain response (CD test)

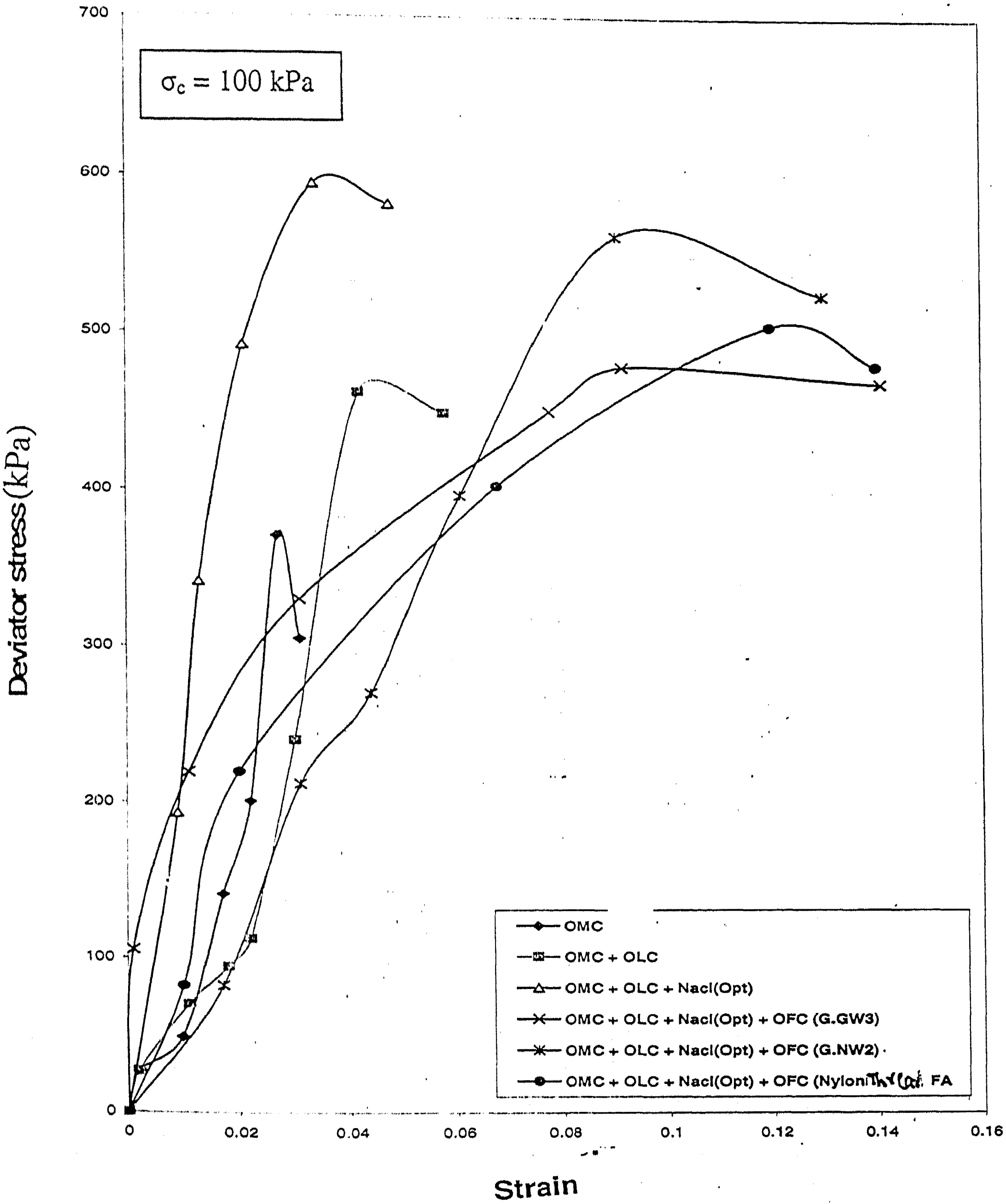


Fig. 3.38 Stress-strain diagram(CU test)

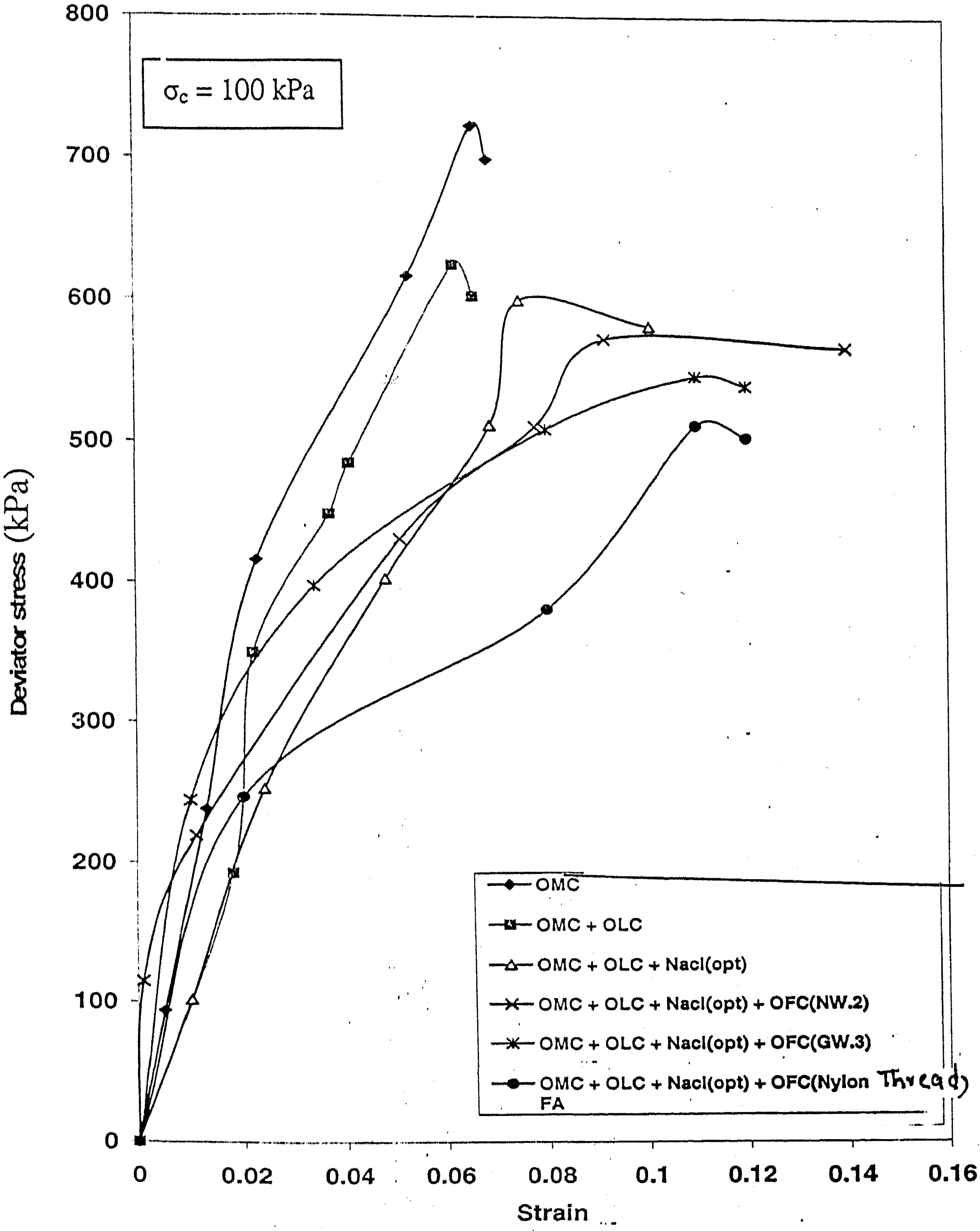


Fig. 3.39 Stress-strain diagram(CD test)

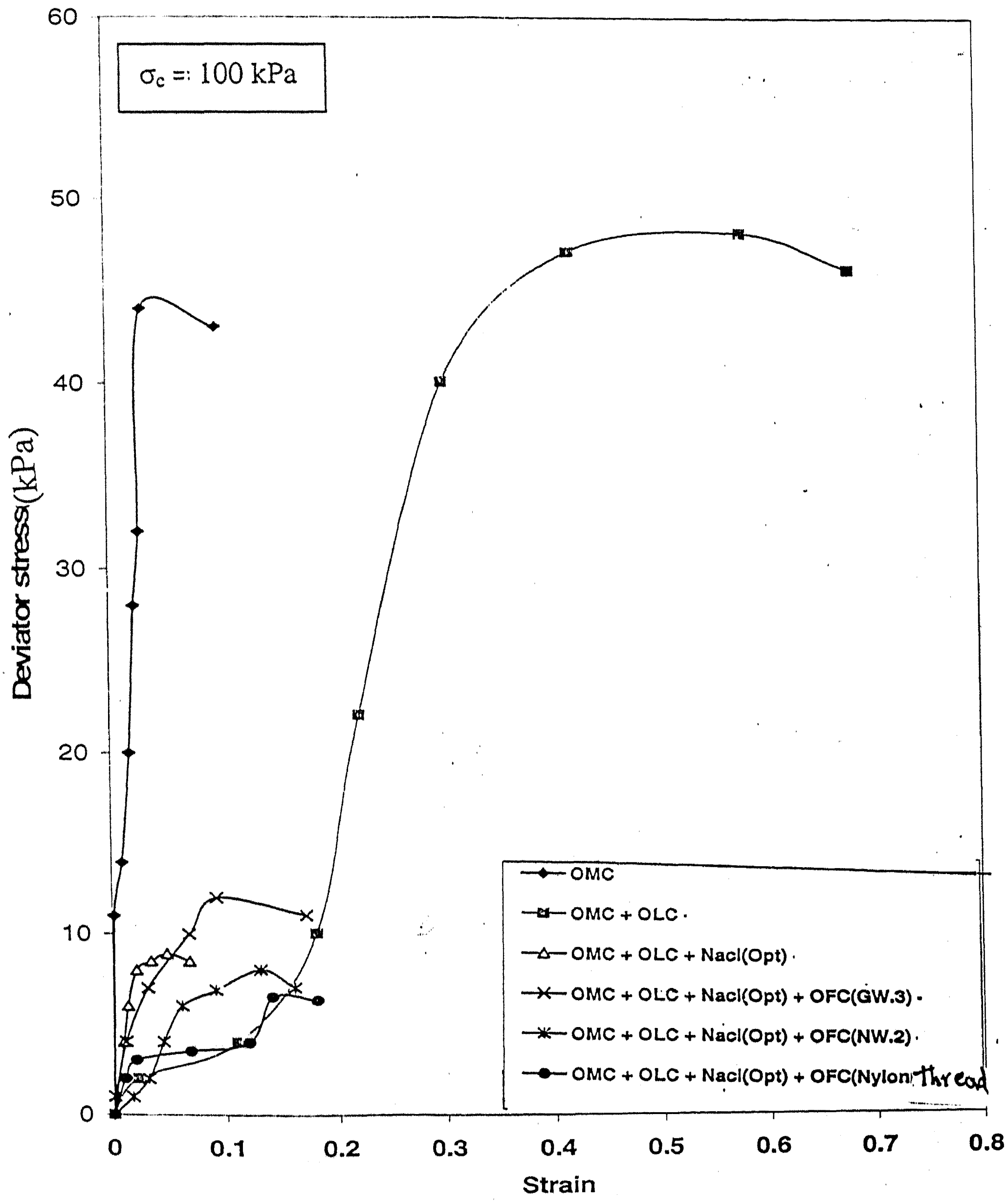


Fig. 3.40 Pore pressure – strain response (CU test) .

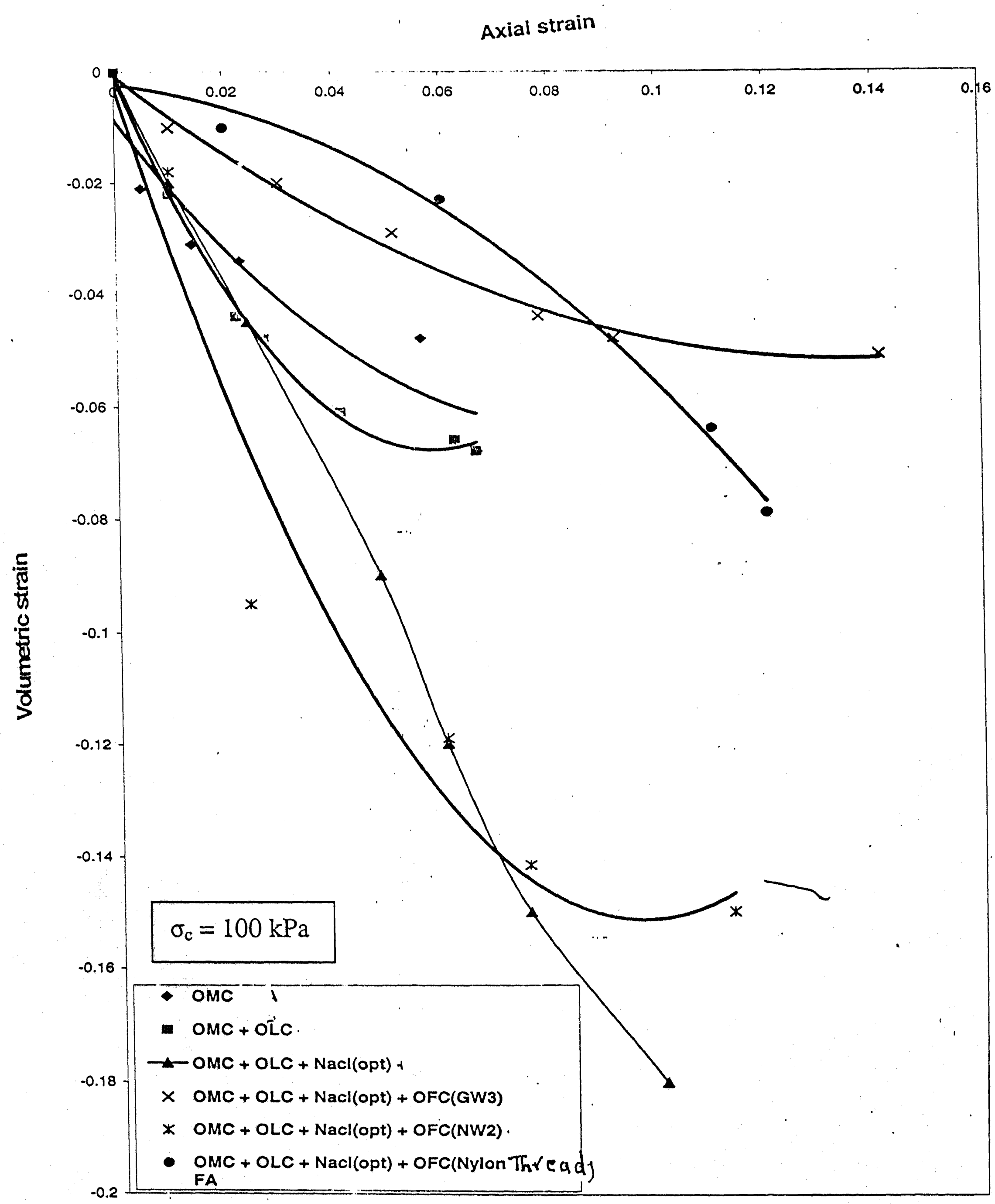


Fig. 3.41 Volumetric strain versus axial strain response (CD test)

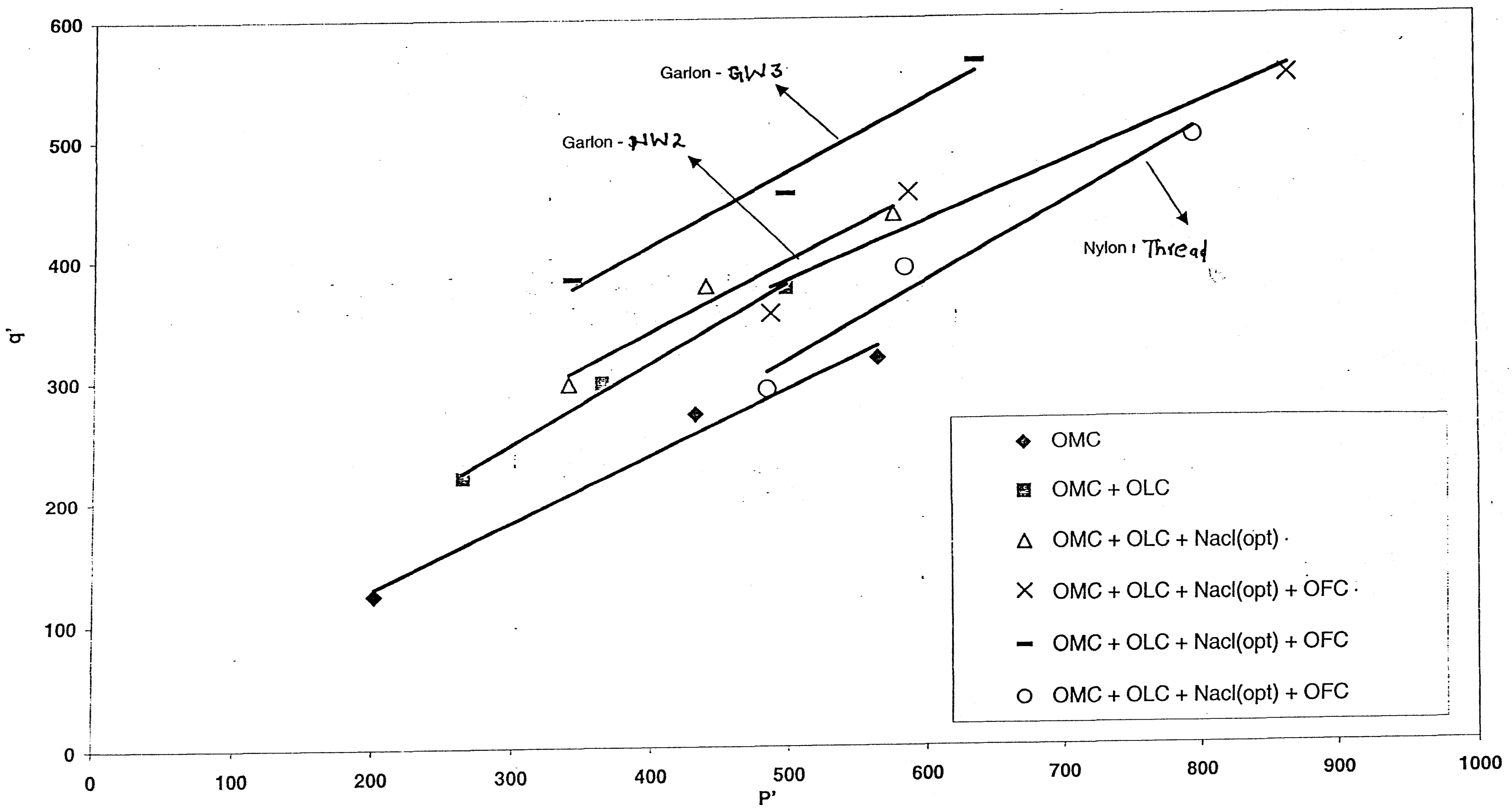


Fig. 3.42 $p^1 - q^1$ diagram (CU Test)

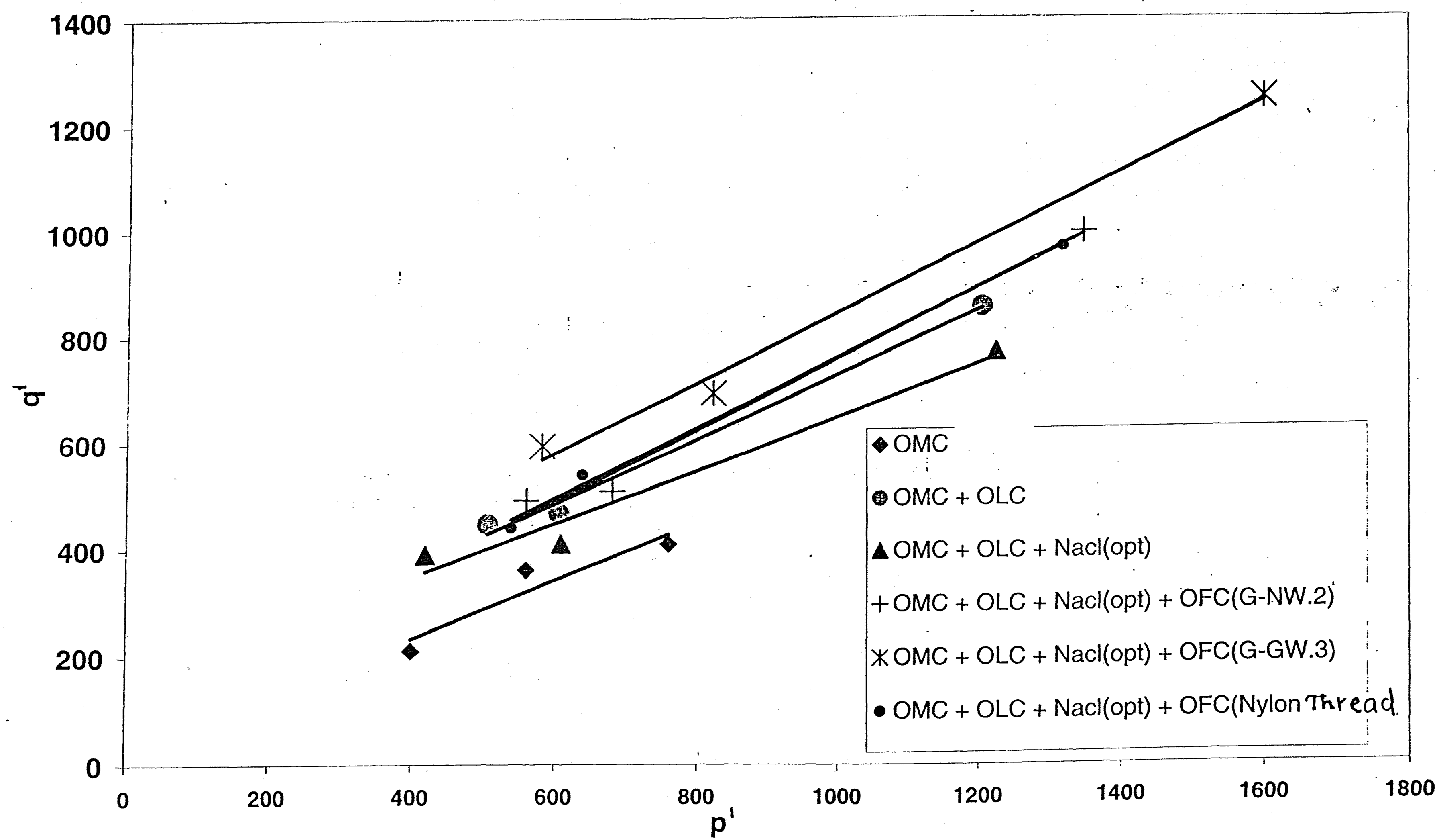


Fig. 3.43 $p^1 - q^1$ diagram (CD Test)

CHAPTER 4

CONCLUSIONS AND FUTURE SCOPE OF RESEARCH:

4.1 Conclusions:

The general conclusions made out of the present study are stated as follows:

1) The Panki lime is of poor quality (Class-F or Low lime flyash) with only 0.8% free lime and, as such, needs stabilization with chemicals and additive of fibers.
2) The Panki pond ash is made up of hollow cenospheres, and, as such, the optimum moisture needed for achieving maximum compaction with maximum dry density is very high (34%). As the particles are hollow it is likely to have low density. This contention is proved by the measured value of maximum dry density of 1.095 gm/cc.
3) Chemical stabilization further increases the strength properties. The salient observations made with the addition of chemicals are:
    i) Optimum lime content is 12% at initial 34 % water content.
    ii) Optimum sodium chloride content at 12 % lime and 34% water is 1%

The maximum gain in strength are as follows

    iii) At 12% lime the maximum value of q_u is 334 Kpa at failure strain 1.79%
    iv) At 12 % lime, 1% sodium chloride q_u is 810 Kpa at failure strain 3%

4) Addition of Synthetic fibers increases the strength substantially as follows:
    i) The optimum fiber content (Garlon-GW3) is 0.6% at 5 mm length with q_u is 3419 Kpa at failure strain 7.05%
5) Addition of synthetic fibers increased the CBR values of Panki pond ash significantly in the range of 7.88% (for fly ash compacted at optimum moisture content) to 25.44% (with chemicals plus Garlon-GW3 filaments) for Unsoaked specimens, where as it was 7.54% to 19.85% with soaked specimens with the same Garlon-Gw3 filaments at optimum contents of chemicals.
6) Effective stress shear strength parameters also increased substantially. The maximum increment in effective cohesion and effective internal friction are as follows

i) The effective cohesion and effective internal friction had increased from 12 Kpa to 220 Kpa and 30^0 to 38^0 respectively in Consolidated undrained case

ii) The effective cohesion and effective internal friction had increased from 16 Kpa to 253 Kpa and 31^0 to 41^0 respectively in Consolidated drained case

7) Increase in strength with Garlon-GW3 is because of the nature of the filaments with gaps in between where the Calcium-Sodium Silicate gel can intrude and form a better bond. Better interlocking of the filaments with the gel formed and sticking of the gel with the particles give to a good composite manifesting in better engineering behavior.

4.2 Future scope of research:

The present work can further be extended to include the following:

i) In addition to the chemicals (quicklime and sodium chloride) and fibers, bitumen and asphalts may be used as admixture to study its effect on the ductility of the composite and on the engineering behavior.

ii) With different admixtures as studied in this thesis or suggested for further work its engineering behavior under repetitive and cyclic loading may be studied to find its suitability under seismic conditions for using constructing roads and embankments.

iii) Prepare data may on the engineering characteristics with different values of the ascertained for finding an optimum combination and simulation using artificial intelligence like ANN models.

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